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International Macroseismic Scale 2025

G. Grünthal, R.M.W. Musson, J. Schwarz,
R. Spence, D.J. Wald, T. Wenk

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Centre Européen de Géodynamique et de Séismologie

Musée National d'Histoire Naturelle
Section Astrophysique et Géophysique, Luxembourg

Preface

The development of the International Macroseismic Scale (IMS-25) was the subject of symposia or sessions at the previous General Assembly of the European Seismological Commission (ESC) 2024 in Corfu, Greece, and the last Scientific Meeting of the International Association of Seismology and Physics of the Earth's Interior (IASPEI) 2025 in Lisbon, Portugal. Both the IASPEI and the ESC support the latest refinement of the macroseismic scale and its dissemination. Representatives from the two institutions will therefore have their own words.

Thoughts by the Secretary General of the IASPEI

Earthquakes shake the solid foundation we live on and have the potential to destroy infrastructure and alter our natural surroundings, resulting in devastation that instills fear. Since the early days, humans have speculated about the origins of earthquakes and reported about felt ground shaking and its effects on people, buildings, and nature. As infrastructure became more complex, it became increasingly important that such reports accurately describe earthquake damage and that people were taught how to avoid damage and casualties.

Already in the dawn of modern natural sciences in the 18th and 19th centuries, scientists began to categorise earthquake damage, by comparing the strength of earthquakes based on their observed effects, and to organise systematic collection of such observations after significant earthquakes. At the end of the 19th century, instrumental observation of seismic waves became reliable and observations were separated into macroseismic (phenomenological) and instrumental data.

Macroseismic studies of historical earthquakes are essential to prolong the period of seismic observations into pre-instrumental times for estimating the seismic hazard of a region, and of modern earthquakes to calibrate such historical data and to investigate site effects to calculate seismic risks. Therefore, the collection and interpretation of macroseismic data remain an important contribution of seismology to making our societies safer.

One of the purposes of the IASPEI is to facilitate the discussion, design, and adoption of standards for observatory practice. Over the last 125 years, IASPEI, its ancestor, the International Seismological Association (ISA), and its regional branch, the European Seismological Commission (ESC), have been strongly involved in defining and updating macroseismic intensity scales and in promoting their application as standards. The definition of such a scale has to be regularly updated to reflect new building techniques, language usage, and the latest earthquake engineering results. The latest update is the European Macroseismic Scale from 1998 (EMS-98). In the USA, the currently used version of the so-called Modified-Mercalli (MM) intensity scale has been outdated for many years.

The International Macroseismic Scale 2025 (IMS-25) presented herein is an extension of the well-established European Macroseismic Scale of 1998 (EMS-98), adapted for the 21st century. It is the final result of decades-long discussions between seismologists and earthquake engineers from the USA and Europe and is anticipated to become the new standard there for the coming years.

I hope that IMS-25 may become a globally adopted standard.

Johannes Schweitzer, IASPEI Secretary General, Kjeller, 28 November 2025

Thoughts by the Secretary General of the ESC

As noted by my colleague and IASPEI Secretary General Johannes Schweitzer, robust quantification of earthquake damage and effects is of core importance for improved understanding of earthquake ground shaking and seismic hazard and risk assessment.

Throughout its history, the ESC has given great significance to this subject: from the endorsement of the MSK macroseismic scale in 1964 to the establishment of the ESC working group on Macroseismic Scales in 1988, which led to the publication of the first version of the European Macroseismic Scale (EMS) in 1992. Following a testing period of three years, the XXV General Assembly of the ESC in Reykjavík recommended the adoption of this new scale by its member countries in 1996, which was then published in its final version in 1998.

In recent years, rapid and spatially abundant macroseismic intensity estimates based on internet questionnaires (e.g., Did you Feel It? by the United States Geological Survey, USGS) or felt reports (European-Mediterranean Seismological Centre, EMSC) have seen increasing prominence. Even the fully automated assignment of intensity values based on social media postings is being explored in today's era of rapid artificial intelligence development. To fully realise their great value in rapid assessment of earthquake impacts, such intensity estimates need to be calibrated to a given, well-defined macroseismic scale. For such a scale, rigorous macroseismic intensity assignments using a robust methodology that considers the strongly varying vulnerability of the built environment and relies on clear damage assessment procedures are absolutely essential. The EMS-98, and now the IMS-25 as its extension and successor, provide exactly this methodology.

Twenty-seven years have passed since the publication of the EMS-98, during which the scale has been widely endorsed and adopted not only throughout Europe, but also worldwide. The IMS-25 builds on the robustness and global reach of the EMS-98, extending it to additional building types and expanded vulnerability classes, and considering the lessons learned from many significant earthquakes since 1998 (e.g., the 2015 Gorkha, Nepal, earthquake, or the 2016-2017 Central Italy earthquake sequence). With the possibility to define National Annexes, the IMS-25 provides all the components required to turn it into a globally accepted standard.

I wish to express my sincere appreciation to the editors and contributors of the IMS-25 and commend them for this great achievement. Finally, while writing these lines in my capacity as ESC Secretary General, I would also like to take this opportunity as Scientific Director of the European Center for Geodynamics and Seismology (ECGS), publisher of the *Cahiers du Centre Européen de Géodynamique et de Séismologie*, to express my delight to see the IMS-25 published as Volume 33 of our *Cahiers* Series.

Adrien Oth, ESC Secretary General, Walferdange, 1 December 2025

Table of contents

Contributors to the International Macroseismic Scale

The working group for the development of the International Macroseismic Scale was active for a number of years, with varying memberships. Those who contributed to the development of the IMS are briefly mentioned below.

As the content and text of this Cahier indicate, the International Macroseismic Scale (IMS) heavily leverages the EMS-98 documentation and the efforts incorporated therein. As is known in the context, the final layout of the European Macroseismic Scale EMS-98 was edited by Gottfried Grünthal, with associate editors Roger M.W. Musson, Jochen Schwarz, and Massimiliano Stucchi, who were all also authors. Specifically, the first three EMS-98 editors and major contributors, together with Robin Spence, David Wald and Thomas Wenk made key contributions to the IMS.

Below, the specific roles and contributions to the IMS are briefly described:

Gottfried Grünthal (Potsdam) provided overall guidance, organised meetings, and co-authored to the IMS text.
Roger Musson (Edinburgh) was a major contributing author to the IMS text.
Jochen Schwarz (Weimar) was a major contributing author, led the efforts of the engineering parts, particularly the building and damage descriptions, the elaboration of Vulnerability Table and damage drawings, contributed to the example collection, and organised meetings.
Robin Spence (Cambridge) provided guidance to the engineering aspects, and was a major contributing author.
David Wald (Golden) coordinated the working group, organised workshops and meetings, and contributed to the writing.
Thomas Wenk (Zurich) provided guidance to the engineering aspects, led the effort on damage photos illustrating the range of vulnerability classes and damage grades, and was a major author of the example compilation.

In this regard, the authors would like to express their gratitude to the following for their helpful contributions: L. Abrahamczyk, A. Charleson, R. Foulser-Pigott, T. Goded, M. Haweyou, A. Hortascu, L.F.G. Lamadrid, S. Lin, S. Loos, P.H. Luqman, K. Porter, V. Silva, E. So, and EMS co-author M. Stucchi. Thanks, also, to all those who provided damage drawings and damage photos. They are acknowledged under their contributions.

Special thanks go to J.W. Kean, K.R. Marra, V. Quitoriano and S. Brzev for their constructive reviews or proofreading with editorial and other suggestions.

Introductory notes
on background, principles and aims of the scale

The purpose of this issue of the Cahier du Centre Européen de Géodynamique et de Séismologie is to present the International Macroseismic Scale (IMS-25) developed by the IMS working group. IMS-25 is not a new macroseismic scale; it is a revision and extension of parts of the European Macroseismic Scale of 1998 (EMS-98)[1], which was also published in this series. The EMS-98 is based on its initial design or test version, the EMS-92[2], and especially on its testing by applying it in major worldwide earthquakes from 1993 to 1998. The EMS-92 itself is based on the scale by Medvedev, Sponheuer and Kárník (MSK)[3], which in turn is relying on the experiences from the application of the Mercalli-Cancani-Sieberg scale (MCS)[4], the Modified Mercalli scale (MMI)[5], and Medvedev's scale from 1953[6].

The EMS-98 is based on a series of innovations that have proven themselves over decades. Thus, large parts of the EMS-98 are incorporated into the IMS-25 virtually unchanged. The list of innovations in the EMS-98, which are acknowledged at the beginning of that edition in 1998, are summarised in Part II, section 1.2. The parts that remain unchanged for the IMS-25 include, e.g., the definitions of damage grades of masonry buildings and those of reinforced concrete, the intensity degrees, the short form of the scale, and a number of sections of the guidelines. In IMS-25 the Vulnerability Table has been substantially expanded, damage levels have now been defined for additional types of structure, and the series of photos of buildings with different vulnerabilities and damage grades have been supplemented with additional examples.

As of this late 2025 writing, it had been over twenty-seven years since the publication of EMS-98. Despite what its eponymous title may seem to suggest, its authors never intended its application to be limited to Europe and in fact its reach is well beyond Europe. The complete English EMS-98 has been translated into four languages, including Chinese, and its short form into 30 languages, e.g., from Arabic to Hebrew, Hindi to Urdu and Vietnamese.

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[1] Grünthal, G., Musson, R.M.W., Schwarz, J., Stucchi, M., 1998, European Macroseismic Scale 1998 (EMS-98). Cahiers du Centre Européen de Géodynamique et de Séismologie 15, Centre Européen de Géodynamique et de Séismologie, Luxembourg, 99 p.

[2] Grünthal, G., Musson, R.M.W., Schwarz, J., Stucchi, M., 1993, European Macroseismic Scale 1992 (up-dated MSK scale). Cahiers du Centre Européen de Géodynamique et de Séismologie 7, Centre Européen de Géodynamique et de Séismologie, Luxembourg, 77 p.

[3] Medvedev, S.V., Sponheuer, W., Kárník, V., 1965, Seismische Intensitätsskala MSK 1964. In: Sponheuer, W.: Bericht über die Weiterentwicklung der seismischen Skala. Veröff. Institut für Geodynamik Jena, Akademie-Verlag Berlin, 8: 12–21.

[4] Sieberg, A.H., 1932, Die Erdbeben. In: Gutenberg, B. (ed.), Handbuch der Geophysik, Vol. IV Erdbeben, Sect. V: 527-686, whereby the Mercalli-Sieberg Scale can be found in Table 162 on pages 552-554.

[5] Wood, H.O., Neumann, F., 1931, Modified Mercalli intensity scale of 1931. Bull Seismol Soc Am 21: 277–283.

[6] Medvedev, S.V., 1953, O novoy seysmičeskoy škale. Trudy Geofizikalni Institut AN SSSR, Vol. 21: 148.

Nonetheless, considering the developments in field work, elaboration tools, the knowledge about world-wide building stock, and not least, the experience and insights from earthquakes themselves, there was recognition of the need for an international scale to better meet global requirements: And there were, in fact, several prior attempts and efforts to develop an IMS.

Earlier efforts towards an International Macroseismic Scale

Current work benefits from past efforts, and several of the luminaries behind the development of EMS-98. Founding members of the EMS-98 working group (G. Grünthal, R.M.W. Musson, J. Schwarz, M. Stucchi) and R. Spence organised the Symposium *Conclusions from 15 years of international experience with the EMS-9*8 at the Vienna Congress on *Recent Advances in Earthquake Engineering and Structural Dynamic*s 2013. As a major outcome and in line with the presentations, they agreed to establish as a joint effort an IMS working group with R. Foulser-Pigott and T. Wenk as further members. Notably, in 2014, agreed modifications to the existing EMS-98 Vulnerability Table were drafted, including expanded types of timber and steel buildings. The first proposed IMS Vulnerability Table built on work by Spence, Foulser-Piggott, and Schwarz. Musson prepared an expanded version of the earlier EMS-98 guidelines in draft 2015.

The IMS working group (in its composition at that time) made essential recommendations concerning adding descriptive diagrams, covering more structural types, damage grades, damage quantities, and summarised basic tasks in a document, which provides the entry for next activities. It was agreed that the illustrations of damage grades in the Core Scale should be updated where necessary and possibly extended to include timber and steel buildings, and that the sample photos in EMS-98 should be extended to cover more structural types and damage grades. These editorial decisions provided the accepted basis for all subsequent working activities and an essential platform for moving forward and reactivating editorial IMS working group activities.

Thereafter, progress towards delivering the IMS was focused on linking World Housing Encyclopedia (WHE) as a complementary database with the development of IMS. A comprehensive study on WHE reports was performed to give a more harmonised assignment of the most likely vulnerability class (as well as their ranges) to the respective types of structures. Criteria for ensuring adaptability to the scale were established.

Another productive effort towards an IMS occurred at the Special Session 96SS *Evolution of EMS-98: Building Types, Vulnerability Classes and Damage Grade Description towards an International Macroseismic Scale* organised by J. Schwarz, T. Wenk, and G. Grünthal at the 16th World Conference on Earthquake Engineering (16WCEE) in Santiago, Chile, 2017. These earlier efforts to envision an IMS, including the 2014 working group and the 16WCEE contributions, did not result in its implementation; nonetheless, their work greatly facilitated the efforts here.

Development of the International Macroseismic Scale

In 2022, the U.S. Geological Survey (USGS) hosted two IMS-related international workshops at the USGS Powell Center for Analysis and Synthesis in Fort Collins, Colorado, albeit with a larger group of participants. Reports were given on these two workshops and a third IMS working group meeting organised by G. Grünthal at the GFZ Helmholtz Centre for Geosciences in Potsdam, Germany, in July 2023, where the IMS working group was formed, being active in collaboration and writing, and contributing in a joint effort to the present version of IMS-25. Results and a compilation of steps contributing to the development and implementation of an International Macroseismic Scale (IMS) are formally adopted in the USGS Open-File Report 2023-1098[7].

It was agreed that by organising and preparing essential papers to 18th World Conference on Earthquake Engineering in Milan, Italy, 2024, the basic innovations of the IMS should be presented. D. Wald, J. Schwarz and V. Silva organised the Session *Macroseismology: Recent State and Future Directions.* The updated version of the Vulnerability Table of IMS-25 (as part of its Core Scale here below) was presented in its first draft as proposed by J. Schwarz, M. Haweyou and T. Wenk. Also, T. Wenk and J. Schwarz provided the new template for the damage examples; previous information on the earthquake, structural type and damage were extended by more detailed comments concerning the classification of damage grade as well as the assignment of the vulnerability class. A next step towards the launching of IMS was reached at 39th Assembly of the European Seismological Commission (ESC2024) with the session *The International Macroseismic Scale of 2024 (IMS-24) - related research and development.*

Main considerations and principles in developing the IMS-25

The main considerations in developing the IMS were:

(i) introducing additional building types, including traditional timber, modern types of timber, reinforced concrete, and steel structures and elaborating an extended Vulnerability Table;

(ii) generating and including tables with drawings for the classification of damage grades for additional building types;

(iii) including an extended set of example illustrations helping to train the assignment of vulnerability classes and damage grades;

(iv) implementing lessons learned from earthquakes and macroseismic observations since 1998;

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[7] Wald, D.J., Goded, T., Hortacsu, A., and Loos, S.C., 2024, Developing and implementing an International Macroseismic Scale (IMS) for earthquake engineering, earthquake science, and rapid damage assessment: U.S. Geological Survey Open-File Report 2023–1098, 55 p., https://doi.org/ 10.3133/ ofr20231098.

(v) providing more insight and an as easy as possible entrance for users without engineering expertise in the evaluation of buildings with Earthquake-Resistant Design (ERD).

Fundamental principles in developing the IMS-25 were, first, not changing the internal consistency with the EMS-98. This would result in intensity evaluations that would be different from earlier applications of the widely used scale. Thus, the IMS-25 maintains backward compatibility and the scale's simplicity so that it not only meets the needs of seismologists alone but also the needs of building inspectors and civil engineers.

Since many European countries and others worldwide have already endorsed and have well-established EMS-98 usage strategies, it can be expected that their approach will hardly need to change with the transition to IMS-25. Yet, the new scale includes new types of structures and damage descriptions, especially earthquake-resistant ones, and several other modifications from EMS-98 may require consideration.

An essential step in EMS-92 was the introduction of the Vulnerability Table, which incorporated engineered and non-engineered buildings into a single framework. The IMS-25 expands this table with further refinements of engineered or earthquake-resistant structures by considering the quality of workmanship, structural regularity, strength of materials, state of repair, and so on, as well as the need to consider such features as relevant for the vulnerability assignment. Additional structure designations include further distinctions among masonry types and separating steel and timber (wooden) buildings to distinguish between those with and without ERD. IMS-25 greatly expands the discussion of ERD and its role in vulnerability class and intensity assignments.

The distinction made with the separation between ERD and lack of ERD for timber allows the potentially least vulnerable class F to be achieved. This accommodates recent analyses in New Zealand and the United States of light and heavy timber frame structures that are rarely used in European countries. For the United States and New Zealand, light and heavy timber, and large residential and commercial wood frame structures are accommodated within the ERD and modern design categories.

The enhanced Vulnerability Table is supported by an extended collection of damage grade descriptions and photo examples. The damage grade descriptions for all the main building structural classes (e.g. masonry, reinforced concrete, steel, and timber) in the Vulnerability Table refer to corresponding overview Tables 4.1 and 4.2. For each damage grade example in section 4.3, uniform descriptions of the types of structure are added directly in accordance with the Vulnerability Table, along with the rationale for assessing them to the individual vulnerability class. Further, each example has a detailed description of the damage grade selection. The sample illustrations prepared exceed the previous EMS-98 collection in terms of quantity and can also be used for training purposes and guidance of the field work.

The IMS more firmly stipulates two subjects of the earlier EMS-98 guidelines. First, IMS-25 further cautions against using ground failure alone (rock falls, liquefaction, lateral spread, faulting) - or ground failure effects on structures - to assign intensities. Building damage must be attributable to shaking, or one cannot directly infer the intensity. Secondly, although the editors kept the classical twelve-degree macroseismic numbering for historical continuity, it should be noted that degrees 11 and 12 are difficult to distinguish apart without building stock of the highest three vulnerability classes. Lastly, guidance and requirements for introducing National Annexes are given.

Structure of the International Macroseismic Scale

Following the Introduction, the IMS-25 consists of Part I, i.e., the Core Scale. It is supplemented by Part II, the guidelines for using the scale, and the short form.

Part I begins with a description of the basic terms used in the scale, starting with the vulnerability of buildings in the form of the indispensable Vulnerability Table. Five damage grades for adobe, masonry, reinforced concrete, traditional and common timber structures are then described and illustrated. The corresponding damage grade tables distinguish between structural and non-structural damage. Damage grades for steel structures are provided in verbal description, only, due to lack of representative illustrations.

Part II gives guidance in assigning the intensity in its chapter 1 and provides the general background in usage of intensity scales in chapter 2. Further on, effects on nature, although these are considered as not integral to the scale, are discussed in section 2.8.

The basic elements of the Core Scale: buildings, vulnerability and damage, are discussed in depth in chapter 3. Types of structures included in the Vulnerability Table are explained in more detail to support the user in assigning the appropriate vulnerability classes.

Chapter 4 provides photos for the classification of damage to buildings. It consists of a collection of about 67 photos of buildings and damage with assigned vulnerability classes and damage grades, helping to support users in interpreting damage and overcoming the limitations of the engineering aspects of intensity assignment.

Those working with written descriptions (e.g., historical documents) or lower intensities only can get by with chapters 1 and 2; those conducting field surveys for higher (damaging-level) intensities require chapters 3 and 4.

The short form of the International Macroseismic Scale, abstracted from the detailed intensity definitions of the Core Scale, is suitable for public communications and educational purposes but not for assigning intensities. The short form of the scale is found at the end of the Core Scale.

Part I The Core Scale: The intensity degrees and related descriptors – vulnerability classes, damage grades, quantities

Like most intensity scales, the International Macroseismic Scale 2025 (IMS-25) provides descriptions of phenomena expected to be observed at a given severity of earthquake shaking. Intensity serves as a measure of earthquake shaking; each successive intensity degree represents a perceptible increase in severity, in steps sufficiently differentiated to be distinguishable: from weak to generally observed, to strong, to damaging, and so on. The basic use of the scale is thus to compare observations made at a place to the descriptions of expected effects for each intensity degree and select the degree that offers the best match to the data. Note that the intention is that intensity should be assigned on the combined observations from a single location, and not on each single report from one observer.

The observations of an earthquake that can be made without the use of instruments rely on various commonly occurring sensors. These fall into four categories: people, objects, buildings, and nature. With successive increases in shaking, (i) more people notice the earthquake, and are progressively more alarmed; (ii) objects such as household furniture are progressively more displaced; (iii) buildings suffer progressively more damage. Effects on nature - such as ground failure - are not explicitly considered as indicators of shaking intensity in the IMS. This is because frequently they are not actually due to shaking at all (fault rupture may be the cause), and even when they are shaking related, the pre-earthquake weakness of the ground (e.g., the propensity for landslides and liquefaction) is inadequately known. As previously mentioned, effects on nature are therefore not integral to the scale or used for intensity assignment, but are discussed in section 2.8 of the guidelines.

Many early intensity scales tended to lump all buildings together irrespective of earthquake resistance; later scales began to differentiate between buildings of varying construction type that offered greater or lesser earthquake resistance. However, the ability of a structure to resist earthquake shaking depends on more than just its building materials. Hence, the use of the concept of vulnerability, is here defined as a series of classes from A (weakest) to F (strongest). The Vulnerability Table is used to assess the class of observed structures. The degree to which a building suffers slight or severe damage is defined by five damage grades, from 1 to 5 in increasing severity.

IMS-25 relies in its descriptions of intensity degrees on the proportion of observations at each locality of any given effect; thus definitions (necessarily flexible ones) are provided of quantitative terms such as “few”, “many” and “most” that are used in the scale. Part I concludes with the actual descriptions of each intensity degree that constitute the Core Scale. For lower intensities, up to 6, effects on people and objects are the most useful. For intensities 6 and upwards, effects on buildings are the most useful.

As already stated above, IMS-25 is to be regarded as an update to the European Macroseismic Scale (EMS-98), which in turn was originally intended as an update to the Medvedev-Sponheuer-Kárník scale (MSK). It was apparent in the testing period 1993-1998 of the EMS-92 scale version that EMS-92 could be applied effectively in other parts of the world. The application of the scale outside of Europe thus has not required extensive revision. The use of the scale with types of structure not covered by the Vulnerability Table is discussed in section 3.8. In addition, their description by a National Annexe is offered and guided by section 3.9.

Intensity values assigned using EMS-98 do not require revision to be treated as IMS-25 values. Also, where mention is made of innovative features in IMS-25, these are innovative with respect to earlier scales and were introduced in the development of EMS-98.

Differentiation of buildings into vulnerability classes

The term "vulnerability" is used throughout this scale to express differences in the way that buildings respond to earthquake shaking. If two groups of buildings are subjected to exactly the same earthquake shaking, and one group performs better than the other, then those buildings that were less damaged had lower earthquake vulnerability than the ones that were more damaged, or it can be stated that the buildings that were less damaged are more earthquake resistant, and vice versa. This is not necessarily the same as other uses of the term "vulnerability" in other contexts.

For modern buildings, especially those of reinforced concrete (RC) the strength of the structure to resist earthquake shaking is strongly dependent on the level of ERD. This is necessarily reflected in the Vulnerability Table on the following page. ERD is discussed in more detail, i.e., with regard to different levels of ERD, in section 3.7. For the optimal use of the Vulnerability Table, information on the types of structures listed here can be found in the guidelines in chapters 3 and 4.

The way in which buildings respond under earthquake shaking depends on the type of structure. Accordingly, the Vulnerability Table is classified in the following categories: masonry buildings, reinforced concrete buildings and buildings with steel or wooden frames and walls. Furthermore, in a general way, a distinction can be made between structures in which the walls are force-bearing (and therefore damage to walls is structural) and those in which the walls are infills (in this case, wall damage alone is non-structural).

Vulnerability Table

Type of Structure		Abbrev.	Vulnerability Class					
			A	B	C	D	E	F
MASONRY	Rubble or Field Stone	M1	○	⋯				
	Adobe	M2	○	—				
	Simple Stone	M3	⋯	○				
	Massive Stone	M4		—	○	⋯		
	Manufactured units with timber floors	M5	⋯	○	⋯			
	Manufactured units with RC floors	M6		—	○	⋯		
	Reinforced or Confined	M7			⋯	○	—	
REINFORCED CONCRETE (RC) (Cast-in-situ)	Frame	RC1	⋯	—	○	⋯		
	Frame with moderate level of ERD	RC1-M		⋯	—	○	—	
	Frame with high level of ERD	RC1-H			⋯	—	○	—
	Wall	RC2		⋯	○	—		
	Wall with moderate level of ERD	RC2-M			⋯	○	—	
	Wall with high level of ERD	RC2-H				⋯	○	—
	Dual System	RC3		⋯	○	⋯		
	Dual System with moderate level of ERD	RC3-M			⋯	○	⋯	
	Dual System with high level of ERD	RC3-H				⋯	○	⋯
	Flat Slab	RC4	⋯	○	—	⋯		
RC (Precast)	Frame	RC5	—	—	○	⋯		
	Frame with moderate level of ERD	RC5-M		—	—	○	⋯	
	Wall or Dual System	RC6		—	○	⋯		
	Wall or Dual System with moderate level of ERD	RC6-M			—	○	—	
STEEL	Frame	S			⋯	○	—	⋯
	Frame with moderate or high level of ERD	S-M/H				⋯	○	—
TIMBER	Traditional	T1		—	○	—		
	Frame or Wall	T2		⋯	—	○	—	
	Frame or Wall with moderare or high level of ERD	T2-M/H				⋯	○	—

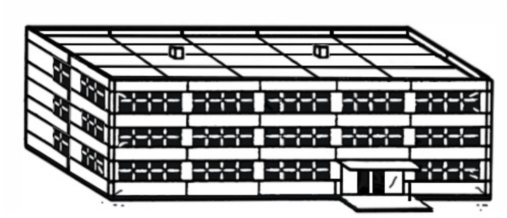
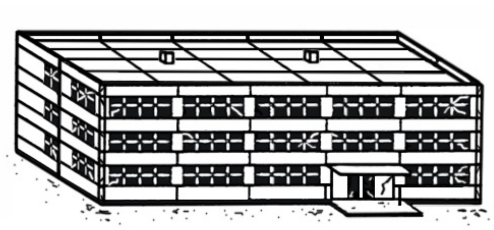
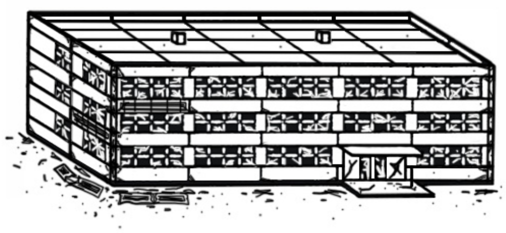
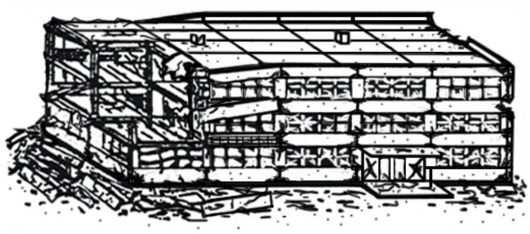
○ most likely vulnerability class — probable range ⋯ less probable, exceptional cases

M in abbreviations refers to moderate level of Earthquake-Resistant Design (ERD)
H in abbreviations refers to high level of Earthquake-Resistant Design

Damage grades for different building types

Classification of damage to adobe buildings	
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Hair-line cracks in few walls. Fall of small pieces of plaster.
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Large and extensive cracks in most walls. Fall of parts from walls. Roof tiles detach. Chimneys fracture at the roof line; failure of few non-structural elements.
	**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Serious failure of walls; partial collapse of outer bearing walls. Partial structural failure of roofs and floors.
	**Grade 5: Destruction (very heavy structural damage)** Total collapse.
Drawings: E.T. Kenjebaev, A.S. Taubaev, Almaty	

Classification of damage to masonry buildings	
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Hair-line cracks in few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in few cases.
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of few non-structural elements (partitions).
	**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.
	**Grade 5: Destruction (very heavy structural damage)** Total or near total collapse.
Drawings: E.T. Kenjebaev, A.S. Taubaev, Almaty	

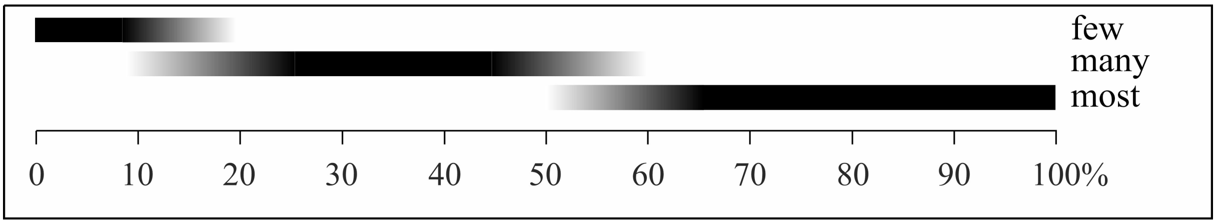
Classification of damage to buildings of reinforced concrete	
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Fine cracks in plaster over few frame members or in few walls at the base. Fine cracks in partitions and infill walls.
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in many columns and beams of frames and in many structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling of mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Cracks in most columns, in most structural walls and most beam-column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of vertical reinforcement bars. Large cracks in partition and infill walls, failure of few infill panels.
	**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforcement bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5: Destruction (very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.
Drawings: E.T. Kenjebaev, A.S. Taubaev, Almaty	

<table>
<tr><th colspan="2">Classification of damage to timber buildings</th></tr>
<tr><td></td><td>Grade 1: Negligible to slight damage
(no structural damage,
slight non-structural damage)
No damage to structural frame. Few hairline cracks in internal walls.
Fall of small pieces of plaster. Few hairline cracks in masonry chimneys</td></tr>
<tr><td></td><td>Grade 2: Moderate damage
(slight structural damage,
moderate non-structural damage)
Little damage to structural frame.
Small cracks in plaster or plasterboard edges; cracks in brick veneers; cracks in masonry chimneys.</td></tr>
<tr><td></td><td>Grade 3: Substantial to heavy damage
(moderate structural damage,
heavy non-structural damage)
Visible frame distortion. Some shifting of unsecured foundations.
Veneers fail and expose frame.
Large cracks in plaster or plasterboard edges.
Roof tiles detach. Chimneys fracture at roof line. Failure of few partitions and masonry claddings.</td></tr>
<tr><td></td><td>Grade 4: Very heavy damage
(heavy structural damage,
very heavy non-structural damage)
Serious frame distortion. Houses not secured to foundations, shifted off. Broken braces. Visible sliding of upper floors. Large cracks in infill masonry. Extensive failure of brick veneers. Non-braced cripple walls fail. Toppling of most masonry chimneys.</td></tr>
<tr><td></td><td>Grade 5: Destruction
(very heavy structural damage)
Total or near total collapse. Large lateral dis-placements. Structure may slide and fall off foundations.</td></tr>
<tr><td colspan="2">Drawings: M. Falck, J. Schwarz, Weimar</td></tr>
</table>

Classification of damage to timber buildings (Bahareque type*)	
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** No damage to framing elements. Fine cracks in very few walls. Fall of pieces of plaster.
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Little damage to framing elements. Cracks in many walls. Fall of fairly large pieces of plaster; the mesh of wooden or bamboo bars is visible.
	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Visible distortion. Large and extensive cracks in most walls; disconnecting of the wood mesh in some areas. Fall of parts of clay infills.
	**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Moderate drift of the whole building. Partial collapse of bearing walls. Collapse of outer, non-structural walls. Roof beams and elements fall down.
	**Grade 5: Destruction (very heavy structural damage)** Serious shifting of the whole building (non-repairable). Collapse of particular parts or of the whole building.
*Timber framing and infills with a mesh of wooden or bamboo bars and clay, refer to Fig. 4-60.	
Drawings: M. Falck, J. Schwarz, Weimar	

Classification of damage to steel structures
Grade 1: Negligible to slight damage **(no structural damage, slight non-structural damage)** Fine cracks in plaster over steel frame members or at the base. Fine cracks in partitions and infill walls.
Grade 2: Moderate damage **(slight structural damage, moderate non-structural damage)** Few cases of failure or distress of frame members, bracing members or structural connections. Cracks in partition and infill walls; failure of brittle cladding and plaster. In light steel frame structures a few rod braces may have yielded.
Grade 3: Substantial to heavy damage **(moderate structural damage, heavy non-structural damage)** Limited but visible leaning of the building or individual storeys; some broken or buckled members in roof trusses; some distortion of columns or damage at connections; failure of some bracing members. Large cracks in partition and infill walls; failure of individual infill panels. In light steel frame structures many braces have yielded. Masonry infilled frames may exhibit crushing of masonry around beam-column connections.
Grade 4: Very heavy damage **(heavy structural damage, very heavy non-structural damage)** Serious leaning of the building or individual storey. Many members and/or connections fail. Roof members shift away from bearing; major distortion of columns. In light steel frames structures, most masonry infill walls exhibit large cracks. Masonry infill walls may bulge out-of-plane, and some masonry or large panel elements may be dislodged or overturn and tumble.
Grade 5: Destruction **(very heavy structural damage)** Collapse or partial collapse of entire structure. Large lateral displacement of remaining elements.

Definition of quantities



Intensity degree definitions

Arrangement of the scale

a) Effects on humans.

b) Effects on objects inside, on liquids and water in tanks as well as on objects outside like tombstones or monuments.

c) Damage to buildings.

Introductory remark: The single intensity degrees can include the effects of shaking of the respective lower intensity degree(s) also, when these effects are not mentioned explicitly.

I. Not felt

a) Not felt, even under the most favourable circumstances.
b) No effect.
c) No damage.

II. Scarcely felt

a) The tremor is felt only in isolated instances (< 1%) by individuals at rest and in a specially receptive position indoors.
b) No effect.
c) No damage.

III. Weak

a) The earthquake is felt indoors by a few. People at rest feel a swaying or light trembling.
b) Hanging objects swing slightly.
c) No damage.

IV. Largely observed

a) The earthquake is felt indoors by many and outdoors only by very few (< 3 %). A few people are awakened. The level of vibration is not frightening. The vibration is moderate. Observers feel a slight trembling or swaying of the building, room, or bed, chair.
b) Dishes, glasses, windows and doors rattle. Hanging objects swing. Light furniture shakes visibly in a few cases. Woodwork creaks in a few cases.
c) No damage

V. Strong

a) The earthquake is felt indoors by most, outdoors by few. A few people are frightened and run outdoors. Many sleeping people awake. Observers feel a strong shaking or rocking of the whole building, room or furniture.
b) Hanging objects swing considerably. Dishes and glasses clatter together. Small, top-heavy and/or precariously supported objects may be shifted or fall down. Doors and windows swing open or shut. In a few cases windowpanes break. Liquids oscillate and may spill from well-filled containers. Animals indoors may become uneasy.
c) Damage of grade 1 to a few buildings of vulnerability classes A and B.

VI. Slightly damaging

a) Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors.
b) Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened.
c) Damage of grade 1 is sustained by many buildings of vulnerability classes A and B; a few of classes A and B suffer damage of grade 2; a few of class C suffer damage of grade 1.

VII. Damaging

a) Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.
b) Furniture is shifted, and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.
c) Many buildings of vulnerability class A suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class B suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class C sustain damage of grade 2.
A few buildings of vulnerability class D sustain damage of grade 1.

VIII. Heavily damaging

a) Many people find it difficult to stand, even outdoors.
b) Furniture may be overturned. Free-standing heavy stable objects (such as IT equipment) fall to the ground. Tombstones may occasionally be displaced, twisted or overturned.
c) Many buildings of vulnerability class A suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class B suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class C suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class D sustain damage of grade 2.

IX. Destructive

a) General panic. People may be forcibly thrown to the ground.
b) Many monuments and columns fall or are twisted.
c) Many buildings of vulnerability class A sustain damage of grade 5.
Many buildings of vulnerability class B suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class C suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class D suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class E sustain damage of grade 2.

X. Very destructive

c) Most buildings of vulnerability class A sustain damage of grade 5.
Many buildings of vulnerability class B sustain damage of grade 5.
Many buildings of vulnerability class C suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class D suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class E suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class F sustain damage of grade 2.

XI. Devastating

c) Most buildings of vulnerability class B sustain damage of grade 5.
Most buildings of vulnerability class C suffer damage of grade 4; many of grade 5.
Many buildings of vulnerability class D suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class E suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class F suffer damage of grade 2; a few of grade 3.

XII. Completely devastating

c) All buildings of vulnerability classes A, B and practically all of vulnerability class C are destroyed. Most buildings of vulnerability classes D, E and F are destroyed. The earthquake effects have reached the maximum conceivable effects.

The short form of IMS-25

The short form of the International Macroseismic Scale 2025, abstracted from the Core Part, is intended to give a very simplified and generalised view of the scale. It can be used for educational purposes. *This short form is not suitable for intensity assignments*.

IMS intensity	Definition	Description of typical observed effects (abstracted)
I	**Not felt**	Not felt.
II	**Scarcely felt**	Felt only by very few individual people at rest in houses.
III	**Weak**	Felt indoors by a few people. People at rest feel a swaying or light trembling.
IV	**Largely observed**	Felt indoors by many people, outdoors by very few. A few people are awakened. Windows, doors and dishes rattle.
V	**Strong**	Felt indoors by most, outdoors by few. Many sleeping people awake. A few are frightened. Buildings tremble throughout. Hanging objects swing considerably. Small objects are shifted. Doors and windows swing open or shut.
VI	**Slightly damaging**	Many people are frightened and run outdoors. Some objects fall. Many houses suffer slight non-structural damage like hair-line cracks and fall of small pieces of plaster.
VII	**Damaging**	Most people are frightened and run outdoors. Furniture is shifted and objects fall from shelves in large numbers. Many well-built ordinary buildings suffer moderate damage: small cracks in walls, fall of plaster and parts of chimneys; older buildings may show large cracks in walls and failure of infill walls.
VIII	**Heavily damaging**	Many people find it difficult to stand. Many houses have large cracks in walls. A few well-built ordinary buildings show serious failure of walls, while weak older structures may collapse.
IX	**Destructive**	General panic. Many weak constructions collapse. Even well-built ordinary buildings show very heavy damage: serious failure of walls and partial structural failure.
X	**Very destructive**	Many ordinary well-built buildings collapse.
XI	**Devastating**	Most ordinary well-built buildings collapse, even some with moderate level of earthquake-resistant design are destroyed.
XII	**Completely devastating**	Almost all buildings are destroyed.

Part II Guidelines for using the scale

1 Assigning intensity

1.1 The nature of intensity

Intensity is here considered a classification of the severity of the ground shaking based on observed effects in a limited area. Intensity scales, and the concept of intensity itself, have been evolving over the last almost 200 years. From a pure hierarchical classification of effects, it has been tried, more and more, to develop intensity as a rough instrument for measuring the shaking; at least, it has been used in this sense.

It follows that an intensity scale is in some ways similar to a shorthand system, in that it allows the compression of a verbose description of earthquake effects into a single symbol (usually a number). Describing intensity in this way is useful to represent the limitations of the concept. Intensity is descriptive in the manner of a prose account, rather than analytical in the manner of an instrumental measurement. Intensity is capable of analysis and interpretation, is indeed a very useful parameter, and its uses go beyond what could be done with a simple compilation of descriptions. But its basic nature needs to be kept in mind by the user so as not to overload the concept with expectations that it cannot meet.

Any intensity scale consists of a series of descriptions of the effects of different degrees of earthquake shaking on a number of elements that may be found in an everyday environment. These elements can be considered as sensors, since their response to the shaking is used to measure the severity of the shaking. But they are not items of special equipment that must be deployed by the observer or investigator; because they are part of the normal environment, these sensors are very common. This is one of the advantages of intensity as a tool: it requires no instruments to measure it. The sensors that have been used historically in intensity scales can be broken down into four groups:

Living things. People and animals. As intensity increases, a greater proportion of people or animals (a) notice the shaking, and (b) may be frightened by it.

Ordinary objects. As intensity increases, greater numbers of ordinary domestic items (such as glassware, books, or objects on shelves) begin to shake and are upset or thrown down.

Buildings. As intensity increases, buildings become progressively more severely damaged.

The natural environment. As intensity increases, there is an increasing likelihood of effects such as liquefaction, cracks in embankments, landslides and rockfalls.

The IMS-25 concentrates chiefly on the first three of these four groups. The fourth is less reliable, as is explained in section 2.8.

Any particular effect on one of these sensors can be considered a diagnostic. For example, "a few people are frightened and try to run outdoors" is a particular reaction by one of the possible sensors (people) and is considered by the intensity scale to be a diagnostic for shaking of degree 5. The description of one intensity degree will be made up of several of these diagnostics, which are considered by the authors of the scale to represent the same severity of shaking.

When the user of the scale has gathered all the descriptive data available for a particular place from a particular earthquake, to assess the intensity that was experienced at that place, they must compare the data to the groups of diagnostics and decide as to which provides the best fit. This, in the simplest terms, is how an intensity scale is used to assign intensity.

The IMS-25 scale recognises the statistical nature of intensity, that is, that at any place a certain effect is likely to be observed in a proportion of cases only, and whether that proportion is small or large is itself something that tells one about the severity of shaking. Earlier scales often described only effects, with no quantities, implying that the same effect was universal.

1.2 The main advances from early scales to the IMS-25 intensity scale

The IMS-25 intensity scale, like the MSK and EMS-98 scales which preceded it, is one of a family of intensity scales which originated with the widely used simple ten-degree scale by De Rossi and Forel[8], this was revised by Mercalli[9], subsequently expanded by Cancani[10] to twelve degrees, and then defined in a very full way by Sieberg, whose scale became known as the Mercalli-Cancani-Sieberg (MCS) scale. It is this scale which forms the starting point not only for the numerous versions of the "Modified Mercalli" scale, but also for the MSK, EMS-98 and IMS-25 scales. Most of these twelve-degree scales are roughly equivalent to one another in actual values. They vary in the degree of sophistication employed in the formulation.

The major difference between the EMS-98/IMS-25 scale and previous intensity scales is in the detail with which different terms used are defined at the outset, in particular, building types, damage grades, vulnerability classes and quantities, and these are now considered individually. The scale adopts the essential innovations that were introduced by the EMS-92, which for the first time consistently builds on vulnerability classes with respect to building damage from intensity 5 upwards and was the first intensity scale to include drawings to illustrate the degrees of damage of different building types and photos to clarify the classification of damage to building types.

The IMS-25 expands the Vulnerability Table to a wider range of structures and includes an expanded collection of photos in section 4, which are used to demonstrate visually what is

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[8] The "Échelle De Rossi-Forel, 1882" was published independently by both authors:
- De Rossi, M.S, 1883, Programma dell'Osservatorio ed Archivio Centrale Geodinamico presso il R. Comitato Geologico d'Italia. Bolletino del Vulcanismo Italiano, 10/3-5, 3-128.
- Forel, F.-A., 1883, Les tremblements de terre orogéniques étudiés en Suisse. Revue d'astronomie populaire, de météorologie et de physique du globe, ii, 449-454.

[9] Mercalli, G., 1897, I terremoti della Liguria e del Piemonte. Stabil. Tipogr. Lanciano e Pinto, Napoli, 146 p.

[10] Cancani, A., 1904, Sur l'emploi d'une double échelle sismique des intensités, empirique et absolue. Beitr. Geoph., Suppl. Vol. II, A 10, 281-283.

meant by the different damage grades. The use of illustrations is intended to improve the consistencies between individual practitioners in the use of the scale. Similarly, the addition to the scale of these guidelines (another EMS-92 innovation) should reduce ambiguities and clarify the intentions behind the construction of the scale.

1.2.1 Building types and vulnerability classes

In a very simple intensity scale, all observations of damage to buildings of a particular type would be grouped together irrespective of the resistance of the building to damage. This would be easy to use but might give very misleading results in an area where contrasting types of building were present. At the other extreme, one can imagine an intensity scale such that it would be necessary to know the exact engineering parameters of a building before one could assess the shaking that had produced the observed damage. This might be accurate, but impossible to use in practice.

The IMS-25 incorporates a compromise, in which a simple differentiation of the resistance of buildings to earthquake generated shaking (vulnerability) has been employed to give a robust way of differentiating the way in which buildings may respond to earthquake shaking. The Vulnerability Table is an attempt to categorise the resistance of structures in a manageable way, taking both building type and other factors into account. This is a development from previous scales which used only construction type as an analogue of vulnerability.

The use of letters to stand for various types of building originated with Richter's 1956 version of the Modified Mercalli[11] scale, and this was also used in the MSK scale in 1964. This subdivision is not made out of architectural interest; it represents, approximately, different levels of vulnerability. The same degree of shaking that will destroy an adobe hut will have much less effect on a well-constructed modern office building. It is clear, though, that the condition of a building, and other factors besides building construction type, also affect its vulnerability. In the opinion of the authors of the EMS-92 scale, experienced seismologists and engineers using the MSK scale were already, in current practice, adopting unofficial modifications to deal with aspects of vulnerability beyond simple consideration of construction type. Thus, some modifications to the treatment of vulnerability needed to be introduced into the EMS-92 scale to make explicit what was already being used as best practice, and this is carried on into IMS-25.

Vulnerability class modifications can be visualised graphically in the Vulnerability Table. For each building type included in the table, a solid line shows the most likely vulnerability class(es) for it, and the probable range is shown as a dashed line. The position of the vulnerability class, along this line must be found by considering additional factors such as state of disrepair, quality of construction, irregularity of building shape, level of ERD, and so on.

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[11] Richter, C.F., 1958, Elementary seismology, Freeman, San Francisco. 768 p.

1.2.2 Damage grades

The damage grades are also something of a compromise. Grades 1 to 5 should ideally represent a linear increase in the severity of shaking. They do this only approximately and are heavily influenced by the need to describe classes of damage which can be readily distinguished by the investigator. One should also note that not all possible combinations of vulnerability class and damage grade are mentioned explicitly for each degree of the scale. Usually only the two highest damage grades for a particular vulnerability class are mentioned; it is assumed that proportionate numbers of buildings will suffer lower grades of damage.

A point which has been inadequately appreciated in the past is that different types of buildings respond and fail in different ways, and this has been addressed in IMS-25 by giving separate accounts of damage to different building types. Locations of damage and damage patterns may also be different for engineered and non-engineered structures.

One should note the difference between structural and non-structural damage, and carefully distinguish between damage to the primary load-bearing (structural) system and damage to secondary (non-structural) elements like infills, curtain walls or elements of roof construction. In the special case of buildings with ERD one must also distinguish damage in special, designated plastification zones, such as coupling beams in wall structures, joints in buildings of prefabricated wall elements or ends of beams in frame structures.

In considering intensity 5 and 6, no distinction is made between vulnerability class A and B. This is because the occurrence of slight damage to plaster is not affected by the structural difference between the two vulnerability classes.

The classification of structural damage should be evaluated in the most severely damaged storey of a building. If safe, it is useful to examine buildings both inside and out, as outward appearances may be misleading. This is applicable in cases where damage is relatively minor; entering a heavily damaged structure is dangerous and should not be attempted. One should not take into consideration damage caused by earthquake-related phenomena other than the actual strong shaking. Such phenomena include damage caused by mutual pounding of adjacent buildings with insufficient separation, landslides, slope failure or liquefaction. This has been a clear problem in many studies in the past, particularly of historical earthquakes, where extensive liquefaction has caused general destruction, which has been assigned intensities of 11 or 12, although the shaking damage may have been much less. By contrast, damage which is greater than expected due to such factors as resonance conditions, or the strength of the seismic forces exceeding the expected level provided for by the level of ERD is still a direct product of seismic shaking and can be taken into consideration as it is.

In the special case of engineered structures with ERD, the progression of damage with shaking may not increase linearly. This can be justified with respect to modern design principles which are related to the performance of engineered structures under different levels of design earthquake shaking.

One should be aware that when investigating the damage effects caused by an aftershock the buildings may have been more vulnerable than would normally have been the case on account of damage (perhaps not very visible) caused by the main shock. This should be taken into consideration when assessing vulnerability.

1.2.3 Quantities

The use of quantitative terms ("few", "many", "most") provides an important statistical element in the scale. It is necessary to confine this statistical element to broad terms, since any attempt to present the scale as a series of graphs showing exact percentages would be impossible to apply in practice and would destroy the robustness of the scale. But defining these terms numerically is not very easy. If few, many and most are defined as three contiguous ranges of percentages (e.g., 0 – 20 %, 20 – 60 %, 60 – 100 %), the undesirable effect occurs that a small percentage increase in some observation may in one case cross a threshold value and put the intensity up by one degree, whereas in another case the same increase will not cross a threshold and so not have the same effect. Broadly overlapping definitions (0 – 35 %, 15 – 65 %, 50 – 100 %) cause problems of ambiguity for an observed value (e.g., 25 %) in the overlap, and widely separated definitions (0 – 20 %, 40 – 60 %, 80 – 100 %) cause similar problems where a value may be undefined. A compromise solution has been found for this version of the scale, using narrowly overlapping definitions, but no solution is ideal (refer to p. 26). The objective here has been to try and maximise the robustness of the scale, and the definitions of quantity presented here should be used with this in mind. This has been presented, very deliberately, in graphical format to emphasise the way these numerical categories are blurred rather than sharply defined. In such a case as a precisely determined quantity falls into an overlapping area, the user should consider the implications of classing it as one category or the other, in terms of which would be more consistent with any other data available for the same place.

1.3 Intensity and place

Intensity is essentially place-related, and normally can only be considered with reference to a specified place, e.g., "the intensity at Pienza was 5" (or more correctly, "the intensity at Pienza was assessed as 5"). To say, "the intensity of the earthquake was 8", with no indication of place, is an improper usage. (Though one could say that the highest observed intensity of the earthquake was 8.)

It is therefore necessary to sort data by place before one starts to assign intensities. One needs to be sure that (a) all the data to be used in each intensity assignment do come from the same place, and that (b) all the available data for that place have been grouped together. Where the data consist of questionnaires from individuals, or individual field observations, these data should be combined for each place to determine in how many instances a diagnostic was or was not observed.

The concept of intensity revolves around the idea that, for a particular place affected by some earthquake, some level of severity of shaking is typical of what was experienced. This entails, firstly, that the settlement is large enough for a statistically significant sample to be obtained, without being unduly affected by small-scale local peculiarities, and secondly, that it is not so large that genuine local variations are blurred over.

Thus, intensity should not be assigned to a single building or street; neither should a single intensity be assigned to a metropolis or a county. In general circumstances, the smallest place should be no smaller than a village, and the largest no larger than a moderately sized town. Consequently, it is reasonable to assign a single intensity value to, say, Piraeus, but not to the whole of modern Athens. No rigid rules will be stated, since individual circumstances will influence the user in the decisions they make in particular cases.

It is also desirable to assign values to locations which are reasonably homogeneous, especially regarding soil types, otherwise the range of reported shaking effects may be very large. However, this is not always practicable, depending on the precision in the data and how they were gathered. In the case where a town has areas in which the geotechnical conditions are very different (for instance, one half might be on an alluvial bank but the other on a plateau) then different intensity values should be assessed for the two parts of the town independently.

1.4 Establishing the degree

The descriptions for each degree of the intensity scale are idealised "word pictures" of the effects to be expected at each level of intensity. Each effect described in the scale may be considered a diagnostic, or test, against which the data can be measured. Establishing the degree is a matter of comparing the data to the idealised descriptions in the scale and deciding which represents the best match.

It is not to be expected that all diagnostics will be satisfied by the data in all cases; for example, some may simply not be present. It is therefore advisable to adopt a flexible approach in seeking the best fit over the range of data available, rather than attempting to set up rigid formulae that depend on one or two key diagnostics only.

But there is an element of subjectivity in assigning intensity, experienced investigators will rarely find significant disagreements with one another. In the great majority of cases intensity assessment is straightforward; problem cases can always be found, but these are usually exceptional. It is impossible to establish guidelines to cover every eventuality, but the following may be helpful.

In real life, the data available will often not match the intensity degree descriptions in every aspect. In such cases, the investigator must decide which degree provides the best fit to the existing data. In doing so, it is important to look for an element of coherence in the data overall, rather than to rely on any one diagnostic as a yardstick.

It is necessary to be wary of giving too much weight to the occasional extreme observation, which might lead to an overestimation of the intensity at the place in question. For example, over-reliance on damage as a diagnostic has in the past resulted in over-estimation of intensities in cases where isolated, even anomalous, cases of damage have been assessed as intensity 6 or more, even though the mass of other data suggest a lower value.

Where the data consist of textual descriptions, the effects may be reported in terms far from the wording of the intensity scale. In such cases, it may be useful to consider whether the overall tenor of the description compares with the general character of a degree of the intensity scale.

In cases where all local construction is of vulnerability class A and most or all buildings are destroyed, it is not possible to distinguish between intensity 10, 11 or 12. This is a saturation effect which cannot really be avoided in practice. It has been suggested that in some regions where the building stock is particularly poor, that saturation of the scale may set in at even lower values. Sometimes it is not possible to make a definite assignment of intensity and only a range of values can be given. One could therefore conclude, for example, that "the intensity was in the range of 6 to 7 or the intensity was 6 - 7".

1.5 Use of negative information

Information that an effect definitely did not occur is often just as valuable as information that it did occur when determining intensity, and such data should not be neglected. For example, a description "the earthquake was very frightening to the inhabitants of Slavonice, but there was no damage of any kind" is indicative that the intensity was not so high as 6 IMS. However, to assume automatically that an effect did not occur, just because it was not reported, is dangerous and invalid unless there are specific reasons why such an assumption can be justified. If only, "a very frightening earthquake at Slavonice", had been reported the incidence of damage would be unknown unless there were very good reasons for supposing that the author would certainly have known about, and mentioned, damage if it had occurred.

1.6 Invalid inferences

A point which follows from the statistical nature of intensity is that no single effect is ever certain. This is important when attempting to infer a negative, rather than a positive conclusion. For example, the existence of several ancient slender spires in a particular region might be used to suggest that the overall exposure of the region to past earthquakes was fairly low, but it would be unwise to conclude from a single spire that such an intensity value had never been exceeded in the locality during the lifetime of the spire.

1.7 Tall buildings and other special cases

In some cases, it may be inadvisable to attempt to use certain data for assigning intensities. A particular case in point relates to observations from tall buildings. People in upper storeys are likely to observe stronger earthquake vibration than those in lower storeys. Various practices, such as reducing the assigned intensity by one degree for every so many floors, have been suggested, but have never found general favour. Also, since very tall buildings may behave under earthquake loading in particular ways according to the frequency of the shaking and the design of the building, the increase of severity of shaking with elevation may be irregular. The recommended practice is to discount all reports from observers from levels higher than the fifth floor when assigning intensity; although in practice the actual behaviour of individual buildings will vary considerably, especially depending on the height and fundamental period of the building. In general, the user should be more concerned with effects observed under normal circumstances rather than in exceptional cases.

One special case is the situation where the only reports available are from tall buildings, because the shaking was so weak that it was only perceptible on the upper floors of such structures. This sort of case is typical of intensity 2. Assigning higher intensities for the shaking variations observed at different levels in tall buildings is not considered in the IMS-25. As well as the height of buildings, their symmetry and regularity also influence the way they behave in an earthquake (refer to section 3.6). This is particularly true with respect to damage, and affects all types of buildings, not just modern engineered constructions. The more regular and symmetrical the design, the better the building can withstand earthquake shaking.

Observations from special structures, such as lighthouses, radio towers, and bridges should not be used; the same is true normally of monumental buildings (such as cathedrals). Data from observers underground usually indicate reduced shaking; they are also not easily comparable with observations made at the surface and should not be used.

1.8 Effects of soil conditions

No attempt should be made to discard or reduce intensity assignments on the grounds that they were influenced by soil conditions. The increase in shaking due to soil amplification or topographical conditions is part of the effects that intensity is a record of, and part of the hazard to which the built environment is exposed. If anomalously strong effects are reported in alluvial areas distant from other areas where strong effects are observed, the correct procedure is to assign high intensities as merited by the effects. It is then possible to interpret these high intensities as due to the soil amplification (although, of course, this may be only one among several contributory causes). Any other approach contradicts the basic nature of intensity as a measure of the observed effects of an earthquake.

1.9 Notation

It used to be regarded as conventional that intensities be notated in Roman numerals, either to distinguish them more clearly from magnitudes or to stress the integer nature of the scale. Since Roman numerals are hard to handle by computer, this convention has to some extent lapsed. The use of either Roman or Arabic numerals may now be considered a matter of taste.

2 The usage of intensity scales

Traditionally, the use of intensity scales has been chiefly through the media of the questionnaire survey and the field visit, applied immediately in the wake of an earthquake. With an increasing interest in past earthquakes since the mid-1970s, there has been a greater usage of intensity scales as tools to be applied to written materials of a very heterogeneous nature. Also, it is increasingly common for engineers and planners to turn to intensity as part of an approach to building predictive tools for estimating future earthquake losses. The present document is intended as a discussion of the general use of the IMS-25 scale, and not as a complete handbook on macroseismology. However, there are some points that can be made in the present context.

2.1 Observed and extrapolated intensities

Intensity as described in these guidelines, refers entirely to a parameter derived from observational data. It is necessary to mention that on occasion intensity values will be encountered which have not been produced from observations at a place but are extrapolations or interpolations of data from other places. This is most commonly observed in catalogues where compilers have extrapolated from observed values to calculate a presumed intensity exactly at the epicentre of the earthquake. In some circumstances this may lead legitimately to decimal intensities; a published intensity 6.3 should only refer to an extrapolated value, perhaps to be used for prognostication. A discussion of such practices is beyond the scope of these guidelines, but it would be helpful if all intensity values cited which are not derived directly from real observations were distinguished clearly as such.

2.2 Correlations with ground motion parameters

Many attempts have been made to correlate intensity to specific physical parameters of ground motion, especially peak ground acceleration, and some early scales actually included equivalent peak ground acceleration values as part of the scale. Although it is undeniable that the effects observed from which intensity values are deduced are a product of real ground motion parameters, the relationship between them is complex and not amenable to simple correlations; there is also evidence that peak ground acceleration is not the most important single parameter affecting intensity. Correlations between intensity and peak ground acceleration often show very large scattering. A review of research field is beyond the scope of these guidelines. Thus, no attempt to include a comparative table of intensity and ground motion parameters, such as acceleration, has been made. This subject is still an area of active research.

2.3 Correlation with other scales

Ideally one should not try to convert values from one intensity scale to those of another by formula or look-up table, though several such tables have been published. Instead, the data should be re-assessed using the scale in which the results are to be expressed. In practice this is often difficult or impossible, and some sort of conversion factor ends up being applied.

Experience shows that comparing different intensity scales can be far from straightforward, since values often vary more from investigator to investigator using the same scale, than values change from scale to scale if the investigator remains the same. This is particularly true for the main twelve-degree scales because of their essential similarity of outline. If one attempts a comparative evaluation either one highlights small differences in a very literal way, in which case the scale is not being used according to normal practice, and the test is invalidated. Or one uses the scales in a more natural, flexible way, and any differences disappear in the interpretation.

It is intended that there should be no differences between assignments made using EMS-98 and IMS-25. In most cases there should be no difficulty in converting between MSK values and IMS-25 values on the system MSK = EMS = IMS. The most likely difference is that some uncertain values such as 4 - 5 MSK or 6 - 7 MSK would now be assessed more certainly as 4 IMS-25 and 6 IMS-25. Other differences may result from literal or restrictive interpretations of the MSK scale. For example, on a literal reading of the text of the MSK scale, the threshold of damage was intensity 6. Practical experience showed that damage occurs sometimes on occasions when all the other data suggest lower intensities, and investigators who recognised this were allowing for the possibility of intensities being assessed as lower than 6 MSK even when damage was reported. Other investigators who did not make this allowance may find that intensities assessed as 6 MSK may in some cases become 5 IMS-25.

Based on a comparison of scale texts, there should also be equivalence between IMS-25 and most variants of MMI and also MCS. In practice, there may be differences due to practices and interpretation of those scales.

2.4 Quality of intensity assessment and data samples

A point which is often neglected, is that the macroseismic data available to the user are never, or very rarely, a complete record of the effects that occurred during an earthquake. For example, when a town with 20,000 buildings in it is shaken by an earthquake, each one of those buildings will be affected in one way or another. The user may have data from only some few tens on which to base his assessment. In other words, their data are a sample from a complete population of observed effects. It is thus valid to ask: Is this sample representative of the population as a whole or not? The smaller the number of reports, in absolute numbers, the greater the error there is likely to be in the proportion of observers reporting a certain effect, compared to the true proportion that would be observed over the whole town. If the data have been gathered with proper attention to random sampling techniques, then it is possible to calculate statistically this error in the sample. However, this is usually not the case. Those who are involved with gathering and studying macroseismic information can make themselves acquainted with the questionnaire and sampling methodologies that have been developed in the social sciences.

The user may not be able to improve the quality of their data, but they should at least have an idea of what the quality is and be able to communicate this; either by qualifying statements, inclusion of sample sizes (e.g., number of questionnaires), or by the use of some system such as using a smaller font to indicate intensities derived from weak samples.

The problem is likely to be less severe, and may hardly arise at all, in cases where the user has direct control of their data gathering by means of a field investigation. It may be very severe where the data are received second or third hand. A sweeping remark by a journalist about the severity of effects in a town may be based on very little investigation; the report of one observer may be rewritten as if it was typical when in fact it was not. This is often a particular problem with studies of historical earthquakes where the user is dependent on relatively few data which have chanced to survive.

An example may illustrate the point. Suppose the only information from a certain town is that many people found it hard to stand. This is a diagnostic for intensity 7, but without the support of any other diagnostics, is an assignment of intensity 7 justified? It is difficult to lay down precise guidelines as to what is, and what is not, sufficient evidence on which to base intensity assessment. An approach when the data are poor is to mark intensity assessments based on weak data, using 7? or using a smaller font, or some similar form. Alternatively, a quality code can be assigned to each intensity assessment.

2.5 Quality and uncertainty

It will often be the case that no single intensity degree can be decided upon with any confidence. In such cases, it is necessary to decide whether some approximate assessment of intensity can be made, or whether the data are so contradictory that it is better to leave the matter unresolved.

In cases where the data fulfil and exceed the descriptions for intensity 6, but clearly are not compatible with those for intensity 7, the best case is to treat the intensity as being the lower value. It is recommended that the user preserves the integer character of the scale, and not use forms such as “6.5” or “6+” that are undefined in the scale.

Example: a village has 180 (masonry) houses, of which 30 are assessed as vulnerability A and the remainder as B. Of the A class houses, fifteen of them suffer damage of grade 1, ten suffer damage of grade 2, and five are undamaged. Of the B class houses, ten suffer damage of grade 1, five suffer damage of grade 2, and the rest are undamaged. If damage alone is considered, there is more than enough to justify intensity 6, but clearly not enough to justify intensity

7 (only few buildings of vulnerability class B suffer damage grade 2, no building of vulnerability class A is indicating damage grade 3 or even higher). An acceptable shorthand for "buildings of vulnerability class B suffering damage of grade 2" is simply "VC B DG 2". The intensity is best described as 6.

There may still be cases where the data can be interpreted equally well as (for example) 6 or 7 (but clearly not 8). In such cases the intensity should be written as 6 - 7, meaning either 6 or 7; it does not imply some intermediate value. Expressing intensity as a range of values is now quite common practice, especially for historical data which are frequently insufficient to permit better resolution. Wider ranges than spanning two degrees of the scale are possible; one could write 6 - 8, and this does not mean 7. Example: a document says, "in our town chimneys fell down but no houses were seriously damaged". In this limited report there is no indication what was the percentage of chimneys that fell, so the intensity might be 6 or 7; the statement that there was no serious damage indicates that the intensity was not 8. The intensity is 6 - 7.

Vague assignments, such as < 6 (less than 6) or > 7 (more than 7), are acceptable when no greater accuracy is possible. Example: a hypothetical document says, "there was a lot of damage at Cortona". If no other information can be obtained, the intensity is > 6. Theoretically, it could be considered that > 6 can be interpreted as 6 - 12, but from practical reasons some upper limit can usually be inferred.

A further problem is caused by ambiguity in the data; for example, effects on humans may only suggest intensity 6, whereas effects on structures suggest intensity 8, or vice versa. If this problem occurs consistently, it may indicate some significant regional or cultural factor is at work (people more easily alarmed; very poor local construction techniques) which should be taken into consideration. When applying the scale, when individual cases of this sort of problem occur, if no coherence can be discerned then it is necessary to express intensity as a range, as discussed above.

There will always be cases where the data are devoid of detail, or completely contradictory or incredible that no assignment can be made. In such cases, it is necessary to adopt some convention to indicate an observation, for example, a dot, or an "F" for "felt" and make no assignment. If necessary, an explanatory footnote can be attached.

Example: a hypothetical chronicle states, "this earthquake was also at Ravenna, Ancona and Perugia". No intensity can be assigned to these three places, but it should be recorded that the earthquake was felt there with some appropriate symbol (like "F", or a dot). Note that it is not even known whether there was damage or not on this limited information.

A distinction can be made between what can be termed *certainty* and *quality* (both words being used here in a special sense). Cases where the data do not allow a precise assessment of intensity, so that values of 6 - 7 or > 6 are needed, are cases where the intensity value is uncertain. In these cases, there is no doubt that the assigned intensity is the best fit possible to the data, but the data are not sufficiently full to allow one to finalise a single intensity degree.

Cases where the data exactly match the scale but are so few that one cannot be sure that they are representative of all that was observed, are cases where the value is what may be called here of poor quality. An example might be a report that states only "windows rattled in Manchester"; this indicates intensity 4 and no other value, but depending on what else was observed and in what numbers, the actual intensity might well have been anywhere in the range 3 - 5. In this sort of case, one does have a single intensity value from the data, but one feels it might not be the correct one, and that if more data were available the number might change.

It is possible for data to be both uncertain and of poor quality. It is recommended that values that are of poor quality should be flagged in some way if they are to be used at all.

2.6 Limitations of twelve-degree scales

It may be remarked in passing, that although the IMS-25 scale and practically all other more modern scales, except the Japanese JMA[12], have twelve degrees, in practice they tend to function as eight- or nine-degree scales. Intensity 1 means in practice "not felt". Intensity 2 is so weak as to be not usually reported in the past, yet is now widely collected via internet questionnaires. At the other end of the scale, intensity 12 is defined in a manner such that it describes the maximum conceivable effects. As all buildings of vulnerability classes A and B, and practically all of vulnerability class C are destroyed, and only few buildings of vulnerability classes D, E and F are expected to survive, buildings of the highest vulnerability classes (and earthquake resistance) should exist to distinguish the effects.

Whereas in the past, intensities 10 and 11 were difficult to distinguish in practice and intensity 11 was rarely used, the distinction between intensities 10 and 11 has been improved by the consistent introduction of earthquake-resistant buildings in the intensity definitions of the EMS that, in conjunction with the increasing construction of ERD buildings, intensity 11 has become more easily detectable. However, experience at these levels is limited because few earthquakes have caused such heavy, i.e., destructive or devastating, damage to very well-engineered structures. So, in practice, the common "working range" of all these scales tends usually to be from intensity 3 to intensity 10.

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[12] Japan Meteorological Agency (JMA) seismic intensity scale JMA, 1949, in: Kawasumi, H., 1951, Measures of earthquake danger and expectancy of maximum intensity throughout Japan as inferred from the seismic activity in historical times: Bull Earthq Res Ins, 21, Tokyo, 469-481.
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www.jma.go.jp/jma/kishou/know/shindo/kaisetsu.html (in Japanese).
www.jma.go.jp/jma/en/Activities/inttable.html (in English) (assessed both 24 Nov. 2025).

2.7 Assessing intensity from historical records

2.7.1 Historical and documentary data

The term "historical data" is frequently used to mean descriptions of earthquake effects from historical records, that is, written sources prior to the instrumental period. However, important macroseismic data of the same kind are still available, and used, for earthquakes of the 20th century, and even for very recent events.

It is therefore practical to consider historical records and modern written evidence together as "documentary data". This term is used here to differentiate descriptions of earthquake effects written for non-seismological purposes from questionnaire data gathered under the guidance of seismologists. These data from written sources need to be retrieved and interpreted according to historical methods, irrespective of whether they relate to the 1890s or 1980s.

Retrieving and handling documentary records requires care and expertise. In particular, the investigator who processes documentary records must be aware that the information has often arrived with them after a long and complicated itinerary. Therefore, the investigator can start by considering the context of the data in both historical, geographical and literary terms.

Particular attention should be paid to the following points:

(i) The value of the source, considering the motivation for writing and the context in which it has been produced. What is the sensitivity of the source to earthquakes and other natural events? (For example, at lower intensities a personal diary is much more likely to record an earthquake than the minutes of a town council.)

(ii) The context in which the report appears may contain significant information. For instance, a book may contain a short description of earthquake effects in one chapter but include details that correct this information in some respect elsewhere in the volume. If the earthquake report is extracted in isolation, this qualifying information, which may be vital, will be lost. The nature of the wording is also important, and information should not be reduced to a précis in such a way as to remove the nuances of the original.

(iii) The spatiotemporal location of the information. Careless handling here can result in duplication of earthquakes, data on one earthquake being attributed to a different event, or to the right earthquake but in the wrong location. In some cases, data cannot be adequately resolved with regard to place or time or both - in such cases, this has to be clearly indicated when the data are mapped.

2.7.2 Building types (vulnerability classes) in historical records

Historical accounts often report in detail damage to special monumental buildings (castles, churches, palaces, towers, pillars, and so on). Less frequently do they also report the effects on ordinary buildings, which are the only ones which can be used within the framework of the scale. The first kind of data will be discussed below in section 2.7.5, as these buildings pose special problems.

With regard to ordinary buildings, the vulnerability classes of traditional houses range in most cases from A to B, even to C and D (wooden structures). One can make the obvious remark that people used the materials nearest to hand, and that the richer the owner, the better-built and better-maintained his house was likely to be. But in the Middle Ages, for example, most houses in many parts of the world were made of wood, and the transition to masonry was long, and sometimes only partial. Without detailed information, it is very difficult to make any reliable pronouncement on the earthquake resistance of these structures; it is not certain, for instance, if medieval timber structures were as resistant as those known today. Medieval houses surviving to the present day, could be considered the best-built ones (the survivor effect).

Some methods of resolving this problem can be suggested - for instance, if it is believed that the housing type at a particular place and date was either vulnerability class A or B, it is possible to assign intensity assuming A, make a second assignment assuming B, and then use the range of values given by the two assignments. Or it may be possible to consider other cultural factors. If there is evidence that structures were weaker in poor rural areas, it may be reasonable to assume a higher proportion of vulnerability class A in hamlets and B in towns. The notion that the first structures to be damaged are likely to be those in the worst condition, may also help (but should not be used blindly or automatically) to resolve some situations.

When EMS-98 was published, there were some criticisms that it could not be used for historical earthquakes because of the difficulty of assessing the vulnerability of historical buildings, and therefore a scale that made no such requirement was better. However, this criticism may be specious. The apparent ease of use of earlier scales is at the expense of less reliable intensity assessments. It is very easy to put down “intensity 6” the moment the word “damage” appears, but in reality, damage to a dilapidated house and a well-built one should not be associated to the same degree of shaking.

2.7.3 Total numbers of buildings

To assign intensity using the percentage of houses damaged, it is necessary to know not only how many houses were damaged, but also how many were not damaged. The sources of data that describe the damage do not systematically (or often) carry this sort of information. However, information on the total number of buildings in a locality can often be obtained with some success by investigating other kinds of sources, such as demographic studies, topographical works, census data, and so on. In some cases, reliable figures can be found without difficulty.

More frequently it is necessary to make use of extrapolations based on population data with various assumptions and correlations. These figures will carry some uncertainties which have to be considered when assessing intensity, often leading to uncertain estimates.

An additional complication is that the figures available may relate to the territory surrounding a small town, including some villages, hamlets, and isolated houses, although the wording suggests that it is the town itself that is being described. The descriptions of damage can suffer from the same problem. Whether or not this problem can be resolved in individual circumstances, it is as well to recognise that such a situation can lead to misinterpretations of ± 1 degree. In such cases it is probably better to stick to a range of intensities such as 7 - 8.

2.7.4 Quality of descriptions

Documents reporting earthquake effects, depending on their nature, often concentrate on the most remarkable or newsworthy effects to the exclusion of all other details. The silence of a source with respect to minor effects can be due numerous factors and cannot be used as if it was proof that nothing happened other than what is described. Similarly, converse assumptions are also invalid; for instance, there is little sense in making such hypothetical extrapolations as, “if the bell tower was thrown down, then at least some minor damage should have occurred to most of the other buildings”. The only way to improve the data would be by further investigation (and this may be simply unsuccessful).

Information produced a few days, weeks, or even months after the earthquake, from the same or other sources, can be illuminating, either supplying new damage data or indirect evidence of the effects. For instance, evidence that life in a locality is going on much as usual after an earthquake - people are still living and working in their houses, the town council meets as usual, religious services continue - then this may be considered to conflict with a description of damage leading one to believe an intensity of 9.

If the data remain poor after all avenues have been exhausted, then one must take it as it is and assess intensity with an uncertainty range that properly represents the poorness of the data. A standard procedure is to keep a record of how decisions have been reached.

2.7.5 Damage to monumental buildings

Damage to monumental buildings is usually better represented in documentary sources than damage to ordinary houses, for two reasons:

(i) These buildings are more important to the writers of such reports because of their social, economic, symbolical or cultural value.

(ii) The structural and non-structural complexity of such buildings is such that they may be more likely to be damaged than ordinary buildings, even though they may be better built.

This is the case, for instance, when small architectural decorations are dislodged from churches during earthquake shaking which is generally below the level at which damage occurs. One should be careful not to overestimate intensity because of such effects. One should also beware of cases where slender structures like church spires or minarets are thrown down as a result of long-period waves from large distant earthquakes. This does not indicate high intensity.

Monumental buildings are usually unique, or only a few such buildings occur in one place. Therefore, it is impossible to use the data relating to them in a statistical way as the scale requires. Such data must therefore be handled with care, as complementary to other evidence (if available). If only data of this sort are available, intensity ranges should be used to indicate the uncertainty in interpretation.

In some cases, where very detailed damage descriptions are given for a building which still stands and can be investigated, or for which there are detailed descriptions, useful conclusions can be drawn about the earthquake shaking by making a specialist analysis.

2.7.6 The character of historical reports

In practice, even when dealing with historical reports containing little detail, it is often possible to reach a judgement about the intensity with a margin of uncertainty expressed as a two-degree range, by considering the general character of the reports.

The following steps may assist:

1. The earthquake is explicitly stated not to have been observed. The intensity is 1 IMS.
2. The shaking was weak and not generally noticed. The intensity is 2 - 3 IMS. In practice, this is usually 3 IMS, since 2 IMS is so weak as seldom to be reported in documents.
3. The shaking was generally noticed but not damaging. The intensity is 4 - 5 IMS. Distinguishing between 4 and 5 IMS from historical records generally relies on whether people were frightened and whether objects were knocked off shelves, both of which suggest 5 IMS. At 4 IMS reports do not mention physical effects beyond making windows or dishes rattle.
4. The shaking was damaging but not destructive. The intensity is 6 - 7 IMS. If accounts focus on only a few buildings, the intensity is probably 6 IMS; if whole streets suffer damage, 7 IMS is indicated.
5. The shaking was destructive. The intensity is 8 - 9 IMS. It is questionable if intensities higher than 8 IMS can be reliably assigned from historical accounts. Reports that whole towns were wiped out may relate to destruction from liquefaction rather than shaking.

Being able to discriminate these five steps should be adequate for most seismological purposes. Discriminating between intensities 9, 10 and 11 in the past has mostly been important in cases where maximum intensity has been used as a surrogate for magnitude, but this is not as reliable as using observed areas.

2.8 Effects on the natural environment

The effects of earthquakes on the ground, here summed up by the term "seismogeological effects", have often been included in intensity scales, but in practice may be difficult to use to advantage. This is because these effects are complex and are often influenced by various factors such as topographic slope, material susceptibility, and water table level, which may not be readily apparent to the observer. The result is that most of these effects can be seen at a wide range of intensities. It is considered, therefore, that the evidence is insufficient to establish good correlations between these effects and particular intensity grades.

A complaint sometimes heard about EMS-98 is that it is impossible to use in unpopulated areas where there are no buildings. Various remedies have been proposed over the years, none of which are effective in resulting in valid intensity assignments. One can use them to generate numbers, but these may have no relation to what intensity might have been observed. Thus, one may not be able to assign intensities in a remote rural area.

The first thing is to recall that intensity is a measure of earthquake shaking measured in term of its effects. Often, the effects on nature are due to fault rupture, not shaking. A diagnostic sometimes used can be "railway lines are bent considerably out of shape". There are numerous photographs of this effect. But, bent railway lines are due to ground displacement either due to fault rupture or slumping, not shaking alone.

In the case of large cracks in level ground unrelated to mass movement, these again are an effect of fault rupture, not shaking. In such cases, the faulting depth is also relevant. If the rupture does not intersect the ground surface, rupture-related features are impossible. Thus, the absence of such cracks does not set a limit on assignable intensity, it likely just means the rupture was too deep.

An intensity scale may not be "a list of things that happen in conjunction with an earthquake". Many phenomena observed in an earthquake are not actually directly due to shaking, and therefore do not belong in an intensity scale. However, some effects on nature *are* due to shaking, prime among them landslides, rockfalls, and other mass movements. The difficulty is that not all slopes that might be prone to such effects are equal. To write "many landslides occur" is like writing "many buildings are damaged" without specifying the type of building. What were the slopes like – steep or gentle, soil or rock? And critically, what hydrological conditions prevailed at the time? This is not something one can straightforwardly determine, yet has a large effect on slope stability, or if one prefers, the vulnerability of a slope.

Rockfalls, which frequently occur without any earthquake at all, may be easily triggered in one setting where rock faces are weathered and highly vulnerable, and in other cases where the rocks are very coherent, they may be occasioned only by very strong shaking. The conditions affecting such phenomena are not necessarily constant for any particular place; they may depend on the state of the water table or vary seasonally. A weak rock face is more vulnerable to "damage" in the form of rock falls than is a coherent one.

The problem is that one has few options for estimating the vulnerability in the way that one has for buildings. The occurrence of minor slope failures and movements of scree slopes usually indicates at least 6 IMS-25 but has no upper bound.

Also, in many cases, seismogeological effects occur in such a way that they cannot easily be quantified to the same degree as other observations can, and of course, landslides routinely occur with no earthquake at all. What one can say is that, if, in a particular region there is a dense clustering of landslides after an earthquake then one can assume that the shaking was stronger than at other, geomorphologically similar places nearby. But to put a number to this does not give you a reliable intensity.

Reference needs to be made here to hydrological effects, which are shaking-related, but the situation is complicated by the effects of long-period waves, which may originate from distant earthquakes (known as a seiche). Sloshing of lake water, including the appearance of turbidity, may be completely uncorrelated with local intensity, and therefore contribute no usable information. One can state, however, that the starting and stopping of springs is generally indicative of at least intensity 7 and often 8; substantial changes in the level of well water and waves on standing water from local shaking generally starts at around 6 but again, depends on the wavelength of the shaking with respect to that of the water feature.

A particular problem arises with regard to the phenomenon of liquefaction. This is certainly caused by earthquake shaking and can occur at intensities of 6 - 7 or higher, depending on the susceptibility of sediments. What can happen is the following: a seismologist reads an account of a historical earthquake stating that in some town all buildings were destroyed. The seismologist then assigns an intensity of 11 based on total destruction, which is not correct by intensity definition, not realising that the buildings were destroyed by liquefaction, not shaking. The intensity 11 is then converted by some equation into a magnitude 8, and this value is entered into the earthquake catalogue. Then another seismologist reads the catalogue and starts proposing a tectonic explanation for a magnitude 8 earthquake occurring in an unexpected location. And so on – a chain of invalid inferences originating from a failure to distinguish the cause of building damage. There is no simple solution to this, but when dealing with historical accounts that record heavy destruction, one should consider what was the surface geology at the location in question before assigning a high intensity.

3 Buildings, vulnerability and damage

3.1 Building vulnerability in intensity scales – a short historical perspective

The concept of vulnerability is fundamental to the construction of modern intensity scales. The amount of shaking required to destroy a poorly built mud-brick cottage is not the same as that required to destroy a well-built office building, and such distinctions need to be differentiated. This can be compared with the effects of earthquake shaking on movable objects: a pencil sitting on a desk may be rolled off by even slight shaking, whereas the severity of shaking required to throw a desktop monitor on to the floor is much greater. Merely to indicate that "objects were shifted" with no consideration of the type of object would not give an accurate discrimination between different levels of shaking. A similar differentiation is necessary with buildings and building damage.

This was recognised at an early stage in the design of intensity scales. Those early scales which made no distinction of building types were generally those designed for use in geographically restricted areas where it was possible to assume "average houses" without further distinction. Such scales also did not need to deal with areas of extensive RC and steel construction such as modern urban centres. Later scales, on the other hand, that were intended to be applicable to the modern built environment and to be more general in their application, such as the MMI or the MSK scales, had to address the issue carefully. They did so by dividing buildings into different classes based on building type, that is, the construction materials employed for the lateral force resisting system. In this, building type was used as a simple analogue for vulnerability.

In the preparation of EMS-92 it was considered that this approach was no longer adequate, since many practitioners were already making private adjustments to reflect varying quality of construction. It could be an improvement to make this explicit in the scale. This approach has been carried forward into IMS-25 in an expanded way, to reflect the complexities of the modern built environment at the global scale.

The explicit treatment of building vulnerability in EMS-92 and EMS-98 was in direct continuity with the MSK and MMI scales. Building types were not distinguished in those scales out of aesthetic consideration, but because this was an easy way of approaching the problem of vulnerability, even though this word was not explicitly used. However, variations of resistance within any one type of building have often been found to be just as great as those between different building types, and this has in the past led to several problems in assigning intensity. The approach adopted in IMS-25 is also designed to be flexible when it comes to adding new types of building.

3.2 Buildings, vulnerability and damage in IMS-25

The major innovation in moving from EMS-98 to IMS-25 has been in the organisation of material referring to buildings and damage. Actually, EMS-98 was and is far from being a particularly *European* scale, and since its first draft in 1992, has been applied in practically every part of the globe. However, in the challenge of preparing a new scale for international use, it was clear that there were advantages in rearranging and expanding the sections on buildings for the benefit of a global community.

An overview of the treatment of buildings in IMS-25 is as follows:

- The Vulnerability Table provides a high-level classification of building types, and within each group, a list of the most important types found worldwide, with the most likely vulnerability classes and ranges.
- The table of damage grades gives five grades of damage that may be observed after an earthquake. A number of tables are taken with minor modifications from that in EMS-98 with the addition of adobe, timber and steel buildings.
- The scale itself gives the expected quantities of buildings in each vulnerability class to show damage of each grade for any particular intensity.
- Sections 3.4 and 3.7 of the guidelines provide an overview of the general principles behind the treatment of buildings in IMS-25.

Thus, the classification of damage according to five damage grades, together with the differentiation of building structures into vulnerability classes and the definition of quantity, constitute the basis on which IMS-25 handles the higher degrees of intensity.

3.3 Frequency distribution of damage grades

3.3.1 Basic assumptions in damage description

The damage grades should ideally represent an increase in the severity of shaking. Therefore, assumptions concerning the progression of damage versus intensity are ideally linear in the range of the most common earthquake intensities (ranging from 6 to 9) and are extended to Intensities > 11. The basic assumption is that at a given intensity, if a certain proportion of class B buildings suffer moderate damage, then an intensity one degree higher, the same proportion of buildings of class C will suffer the same degree of damage, and so on, i.e., an increase of ground shaking by one intensity degree corresponds to an increase in damage by one grade for the same building type or vulnerability class. Further, the performance of different types or categories of building types is similar, if the same vulnerability class has been assigned.

Over the range of intensities, the quantitative terms for the occurrence of the increasing damage grades remain unchanged with respect to one vulnerability (or building) class. This may not follow exactly in cases where a survey of damage includes buildings of different types that have been differently designed.

3.3.2 Damage functions in macroseismic scales

Early intensity scales, with one exception, generally dealt with damage only in a limited and restricted manner, stating that a certain type of damage to buildings would occur at a certain intensity, implying that the distribution of damage was uniform. The exception in this regard concerned Sieberg's MCS scale versions from 1912[13], 1923[14] and 1932[15], in which he distinguishes, albeit in varying ways, between damage to solid houses and those in poor condition, brick buildings and wooden buildings, especially half-timbered buildings, and whether 1/4, 1/2, or 3/4 of the buildings of a certain type are affected by certain degrees of damage.

The limited and restricted approach of most early scales was mitigated only somewhat by the comment prefacing the MMI scale that any effect could be seen in a weaker form, or in few instances only, at one intensity degree below that for which it was supposed to occur. It was a major step forward when Sieberg's idea of introducing both a qualitative and quantitative approach to damage was further pursued with the MSK scale. With the EMS-98, this approach finally achieved a new level of quality with the introduction of a series of innovations such as vulnerability classes. These innovations were retained and refined in the IMS-25.

In an idealised case, one could consider the distribution of damage to buildings of equal vulnerability subjected to the same intensity as a normal distribution about the mean damage grade. In fact, field surveys indicate that a beta(ß)-distribution might better match the observations (refer to Fig. 3-1). If a more continuous damage function could be plotted, the damage diagnostics given in the scale represent sample points on this curve. One should remember that they are only sample points, and that intersections of other grades of damage on the curve may also be observed. If, for some degree of intensity, it is defined that few buildings of a certain vulnerability class suffer damage of grade 3, while many suffer damage of grade 2, one should remember that observations at the lower end of the distribution will also be encountered. In this case, one might also expect many buildings to suffer damage of grade 1 and a few to be undamaged.

Just as the defined damage grades represent discrete points on a continuous damage function covering every shading from no damage to complete collapse, so the degrees of the intensity scale represent discernible stages of shaking. However, as the damage function has absolute upper and lower bounds, the shape of the damage distribution must change as these bounds are approached. Thus, at low intensities one sees the leading edge of a normal curve at low damage grades, whereas the bulk of the distribution is "piled up" at the point representing no damage, since negative damage degrees are not possible. And similarly, for very high intensities, one should ideally see the trailing edge of the normal curve at high damage grades, whereas the

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[13] Sieberg, A.H., 1912, Über die makroseismische Bestimmung der Erdbebenstärke. Gerlands Beitr. z. Geoph. 11: 227–239.
[14] Sieberg, A.H., 1923, Geologische, physikalische und angewandte Erdbebenkunde. G. Fischer, Jena, 572 p.
[15] refer to [4]

bulk of the distribution piles up at the point representing complete collapse which cannot be exceeded.

This is shown schematically in Fig. 3-1, which illustrates three principal damage functions: a) for lower intensities, where the function shows monotonically decreasing probability of damage at higher grades; b) as being the base case where a distribution of probabilities is observed about the mean damage grade, and c), which is a monotonically increasing probability with increasing grade of damage, typical of the higher intensities.

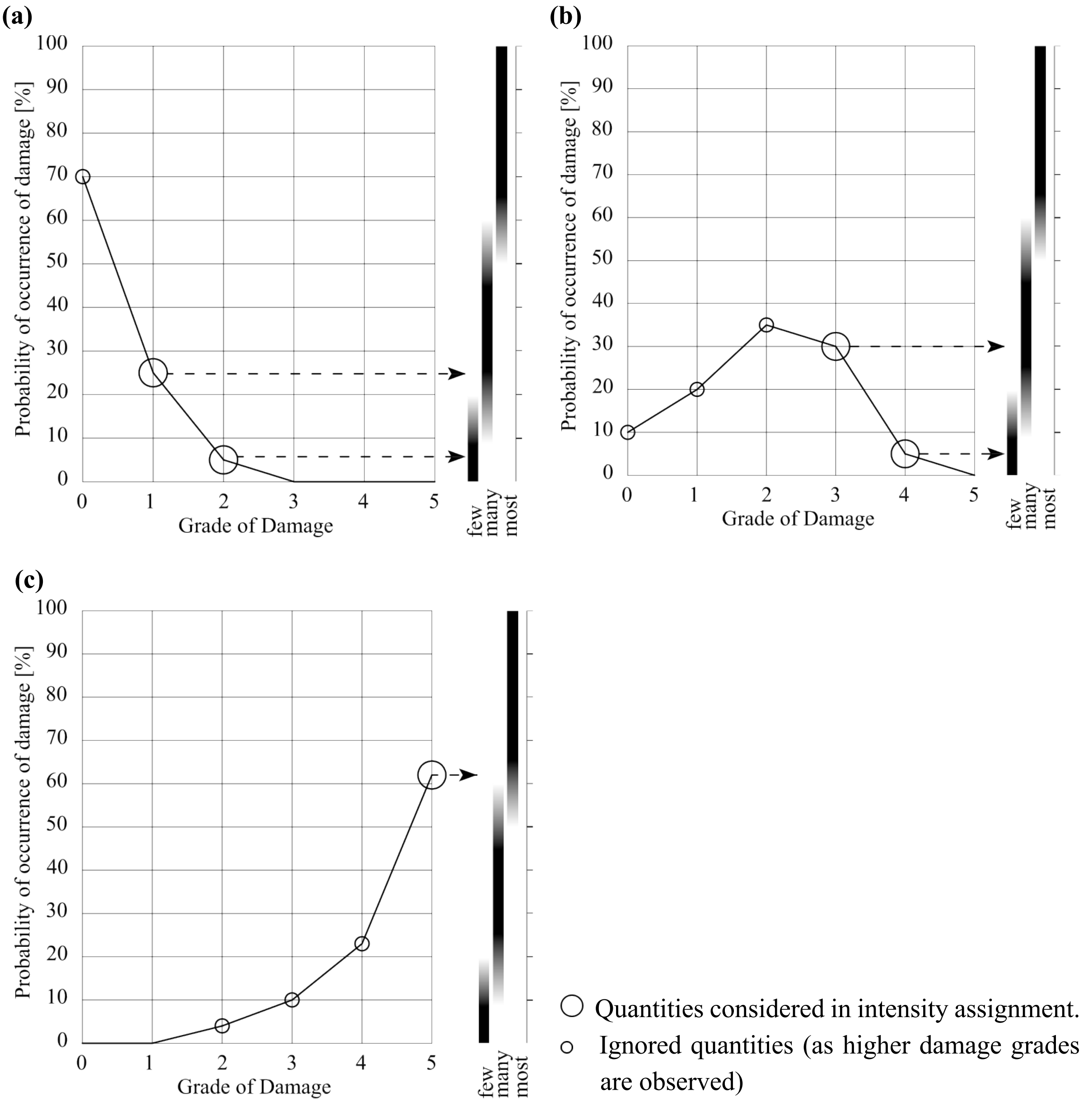


Fig: 3-1 Relation between typical frequency distributions of grades of damage for different intensity degrees and definitions of quantities used in the presented intensity scale:
(a) vulnerability class A or B (assigned intensity: VI), (b) vulnerability class B (assigned intensity: VIII), (c) vulnerability class A (assigned intensity: X).

Relationships between the occurrence rate of damage grades and intensity in terms of damage distribution functions – elaborated for the different building types – might contribute to new descriptions, in particular, for the higher intensities. This applies at least for ordinary masonry buildings; for some building types (especially timber frame houses) the pattern may be different, with a sudden transition from almost no damage to destruction.

The major insight regarding the response of building with ERD is: they are not damage-free. Damage has to be expected. Consequently (and true for buildings of a new code generation), there should be a saturation of damage of grades 2 and 3 in the observations and damage distributions (Fig. 3-1 (b)).

3.3.3 The maximum damage decision for intensity assignment

The definition or description of the intensity degrees in the scale is made by choosing one or two typical intersecting points on these curves for each vulnerability class, where the curve intersects with a particular damage grade. Thus, for example, for intensity 8, for vulnerability class C, the intersecting points on the damage function are those for damage grades 2 and 3; nothing is said about the probability of damage grade 1 or no damage, but these exist and are implied by Fig. 3-1 (a-c). The points given are generally in terms of the highest damage grade or grades to be expected (the "maximum damage decision"); these are likely to be the best reported or examined. The use of statistical results of damage surveys may be the key for correlating particular building types with the most likely or probable vulnerability classes.

Fig. 3-1 shows typical frequency distributions of damage grades for damaging intensity degrees without specifying the different types of buildings. The classification of EMS and IMS intensities degrees is limited to special intersecting points (between the higher grades of damage and the values of the damage probability function) of this frequency distribution. In effect, the shares of observed damage grades for the same type of structure form a continuum from which sample points (expressed as quantities such as "few", "many" and "most") are used to describe intensity.

The task for determining intensity is to quantify the percentages of damage grades for each type of structure. And, this demand should be fulfilled on the basis of two points of the damage frequency distribution curve. Especially in the case of higher intensities, it could be useful to check buildings with minor damage instead of predicting the percentage of buildings with higher grades of damage. Such damage distribution curves can serve as a basis for further refinement of intensity classification and should incorporate results of damage surveys.

In general, a linear progression of damage is observed at the intensity degrees at which damage occurs. If the amount of damage is the same for every increase of one class in vulnerability, the resulting intensity assignment also increases by one degree. These patterns of increasing damage with increasing intensity are derived from observed statistical distributions of structural and non-structural damage.

Although in some exceptional cases irregular damage distributions may be encountered, one should expect that, with high probability, any damage distribution for a particular intensity observed in the field will correspond to those given in Fig. 3-1.

3.4 The structure of the Vulnerability Table

The MSK scale defined building classes by type of construction as a simple attempt to express the vulnerability of buildings. These were denoted as A, B and C, standing for the resistance of a "typical" adobe house, brick building and reinforced concrete (RC) structure. In EMS-92 and now in IMS-25, vulnerability classes A to C are intended to be compatible with the basic MSK classes. Additional classes D and E are intended to represent approximately linear decreases in vulnerability as a result of improved levels of ERD, and also provide for well-built timber, reinforced or confined masonry and steel structures, which are intended to be resistant to earthquake shaking. Class F is envisioned to represent the vulnerability of a structure with a high level of ERD, i.e., a structure of the highest earthquake resistance due to the incorporated design principles. There is insufficient experience to inform possible division of this class.

There has also been some discussion as to whether the original classes of A, B and C should be expanded downwards, that is, by adding a class below A for extremely poor structures, that could be denominated "A minus" or "zero". This has not been done because very poor buildings are hard to treat statistically. One encounters extreme cases of buildings partially collapsing at great distances from an earthquake epicentre, or even collapsing without any earthquake at all. Such effects are hard to systematise in the context of an intensity scale.

For convenience, the major building types listed in the Vulnerability Table are arranged into four higher-level categories as follows:

- Masonry
- Reinforced concrete (cast-in-situ, precast)
- Steel structures
- Timber structures.

When assessing the vulnerability class of a structure or group of structures, an examination of the building construction type enables one to find the correct row on the Vulnerability Table. Once the structural type of a building has been decided, consideration of the factors in sections 3.5 to 3.7 will allow a decision to be made as to the final class.

The circle sign shows the most likely or probable class. If there are no special strengths or weaknesses apparent in a building, this is the class that should be assigned. A solid line shows a probable range up or down. A few strengths or weaknesses will allow the building to be classed within this range. A dotted line shows the range in extreme cases - many strengths or weaknesses, or strengths that are particularly remarkable, or weaknesses that are very severe, allow the building to be classed within this range.

Whereas it would be convenient to have a systematic checklist to follow that would guide one to the appropriate class shifts to apply, in practice it is unlikely that such a list could be constructed that was always reliable, and a flexible approach is to be preferred.

It is important to stress the need for flexibility in the assignment of intensity. To someone used to very simple intensity scales, IMS-25 may appear daunting, and it might be considered that the scale is unusable without detailed engineering knowledge and information. This is not the case. It is always necessary to work with information available and if information on the factors discussed below is lacking, one simply ignores those factors and accepts an element of uncertainty in the final intensity value – which may actually be small, as intensity should be a robust concept. Simplifying assumptions can be made when data are not detailed (for instance when derived from documentary evidence only); but when data are detailed, especially in the circumstances of post-earthquake reconnaissance missions, then all details can be used.

3.5 Descriptions of types of structures listed in the Vulnerability Table

3.5.1 Masonry (M)

3.5.1.1 Rubble stone, field stone (M1)

Rubble-stone or field-stone masonry is a traditional form of construction where rough, unhewn stones as well quarry stones and river boulders are used as the basic building material, usually with poor quality (mud or lime-based) mortar, leading to buildings which have heavy, thick walls with little resistance to lateral loading. Floors are typically of wood, and provide no horizontal stiffening and therefore no resistance to lateral loading. Roofs can be made of almost any material, both lightweight and heavy. The vulnerability class of rubble stone buildings is generally A, but for field stone buildings class B can be assigned if special timber elements are provided (refer to Fig. 4-5).

- Examples for M1: Figs. 4-1 to 4-4 (rubble stone); Figs. 4-5 to 4-8 (field stone).

3.5.1.2 Adobe (M2)

Adobe constructions can be found in many places where suitable soils can be found. Methods of adobe construction vary widely, and this introduces some variations in the resistance against earthquake shaking. The most common form of adobe building is constructed from mud blocks made from a local soil and cast in timber moulds. Sometimes straw or wheat husk are added to the soil to improve cohesion. Masonry walls of thickness from 25 to 80 cm are made from the sun-dried blocks using a mud mortar. Walls built up of layers of adobe without the use of blocks are stiff and weak.

Other forms of earthen construction are found in many areas such as rammed earth construction or wattle and daub, where a wooden frame is filled in with laths covered with clay (refer to section 3.4.5.1). Adobe and earthen constructions may perform better depending on the quality of the mortar, and, to a lesser extent, the quality of the blocks. Most essential is the link between perpendicular walls which can be achieved by simple horizontal timber links to avoid their separation. Additional protection against out-of-plane failure can be achieved by lateral bracing piers or buttresses (refer to Fig. 4-9).

Roofs are generally made from wooden joists, covered by metal sheets or clay tiles and resting on the walls. The weight of the roof is one of the important factors in the seismic performance of such houses, heavy roofs being a liability.

The vulnerability class of adobe and other earthen buildings is generally A, but better built examples may be B. The differentiation into adobe and earthen types of structure does not correspond to the variety of existing realisations, in particular concerning the use of timber elements and their reinforcing or stabilising effect (refer to 3.5.4.1).

- Examples for adobe masonry (M2): Figs. 4-9 to 4-14.

3.5.1.3 Simple stone (M3)

Simple-stone construction differs from field-stone construction in that the building stones have undergone some dressing prior to use. The stones are arranged in the construction according to some techniques to improve the resistance of the structure, such as using larger stones to connect the walls at the corners. The vulnerability class of simple stone buildings is expected to be B, but depending on quality of construction, can be vulnerability class A.

- Examples for M3: Figs. 4-15 to 4-17.

3.5.1.4 Massive stone (M4)

Buildings such as monuments, castles, large civic buildings use stone masonry consisting of large blocks. Special buildings of this type such as cathedrals or castles would not normally be used for intensity assessment for reasons given in section 1.7. However, some cities contain areas of 19th century buildings of this type and therefore this construction type may be significant and could be used for intensity assessment. These buildings usually possess greater resistance, which contributes to the assignment of vulnerability class C (or even D for exceptionally well-built cases).

Existing sub-classification of natural stone wall types can be used to guide the selection of the appropriate vulnerability class using the visible characteristics of stone units, bond, mortar layers and additional (horizontally) stabilising elements or layers (timber, stone). If massive natural stone units are used in edges or in wall connections achieving a framing or confining effect for the weaker material between (refer to 3.5.1.6) they can be regarded as this type of building, too. Different types of floors are applied; RC floors or even steel girders may be expected in rehabilitated buildings.

- Examples for M4: Figs. 4-18 to 4-21.

3.5.1.5 Masonry with manufactured units

This widespread construction type is practiced in many regions regardless of their seismic risk and in both rural and urban areas. This construction type is generally vulnerable to earthquakes but performs better than vernacular unreinforced masonry typologies M1 to M4. Unreinforced load-bearing masonry construction differs from rubble-stone masonry construction as the units are regular shapes; bricks have been moulded, dried and fired and stones have been dressed/ hewn before construction.

Cut stone, brick masonry and/ or concrete blocks are regularly shaped units bonded together with mortar. Effective bonding between mortar and masonry units is used to provide seismic resistance. The shape, size and material of the units and the type of mortar used can vary considerably: Cut-stone masonry is generally made from blocks of locally available natural stone material. Cut-stone masonry houses generally use mortars which are either lime or cement based. Brick masonry is made of clay or loam which is used to form regular-sized masonry units, dried and fired in a kiln. The used stone units are often visible in case of higher damage grades, only.

A variety of roofing systems can be used. These roofing systems including tiled roofs supported on timber trusses, fibre cement or steel sheets on steel trusses, and RC slab (flat or pitched). The vulnerability of buildings is greatly influenced by the types of materials and quality of workmanship as well as the use of the building and the type of floor construction. Recognising their variety (including masonry vaults, composite steel and masonry slabs), two major sub-types are distinguished as described below:

Unreinforced masonry with timber floors (M5)

It is characteristic of this widespread building type that no special attempts have been made to improve the horizontal elements of the structure, floors being typically of wood and therefore flexible. The material type of floors can vary from historic vaulted brick masonry spanning over the ground floor with timber joists and floorboards at the upper floor levels, to timber joists at all levels above ground.

In general, the vulnerability is affected by the number, size and position of openings. Large openings, small piers between openings and quoins as well as long walls without perpendicular stiffening contribute to a more vulnerable building. One problem to watch out for is the use of systems of cavity walls with internal and external wythes, which can, if not properly connected, create very weak walls with insufficient earthquake resistance.

This very common type of construction is the archetypal vulnerability class B type of building against which others can be measured or calibrated. Due to its very commonness one will often encounter specimens in such poor condition that they will count only as class A. It is less common to find examples so well-built as to count as class C, but this may be the case for large houses built to high standards, or built in locations where lateral resistance is needed for wind loading.

- Examples for M5: Figs. 4-22 to 4-30.

Unreinforced masonry with RC floors (M6)
Although the walls of a building are the most obvious part of it to the observer, horizontal elements can actually be more important in determining the resistance of a structure to lateral loading. Hence, the type of construction where the walls are unreinforced masonry but the floors are reinforced concrete, will behave significantly better than unreinforced masonry construction with timber floors.

Where the walls are connected and tied together with a rigid floor slab with ring beams, a box-like system is created which effectively reduces the risk of out-of-plane collapse of walls, or the separation and drift of intersecting perpendicular walls. This improved performance will only be realised if the RC floor is properly connected into the structure, which is not always the case. Where the structure is well connected, the vulnerability is most probably of class C; otherwise of class B.

- Example for M6: Fig. 4-31.

3.5.1.6 Confined and reinforced masonry (M7)
Under confined and reinforced masonry types are found various systems in which significant effort has been made to improve the performance and ductility of masonry construction.

Confined masonry construction consists of masonry sections confined by RC framing elements (tie-beams and tie-columns) which are bonded or connected to the masonry, thus segmenting the masonry walls into smaller panels that are more capable of withstanding earthquake shaking. A key aspect of confined masonry is that the tie-columns are cast in place after the masonry wall construction has been completed.

It is not intended that the connecting elements should perform as a moment-resistant frame, where masonry in most cases would only act as non-structural infills. In reinforced masonry, bars or steel mesh are embedded (in mortar or grout) in holes or between layers of masonry bricks, creating a composite material acting as a highly resistant and ductile wall or wall system. Such reinforcement will be present in both the vertical and horizontal directions. Therefore, the masonry units are either perforated brick or hollow concrete block.

In grouted (multiple-leaf) masonry walls consisting of an outer and inner brick shell are connected with a concrete core vertically and horizontally reinforced. Problems can arise if the bond between shells is insufficient. The overall performance of such systems should also be equivalent to reinforced masonry, although experience with this form of construction is limited so far.

Special stone systems, where a set of special shaped (e.g., interlocking) building stones are formed out of concrete, and might perform well. Both confined and reinforced masonry are most probably of vulnerability class C, with better examples reaching vulnerability class D.

- Example for M7: Fig. 4-32.

3.5.2 Reinforced concrete (RC)

Reinforced concrete construction, now so prevalent in modern cities, varies greatly in appearance, design and resistance, making it difficult to present a simple guide as to how to deal with such structures. The Vulnerability Table follows a primary sub-division between reinforced concrete frame, wall and dual-system structures, and also distinguishes between cast-in-situ and precast structures. In the Vulnerability Table, a further differentiation refers to the level of ERD. The step-wise procedure for assignment is explained in section 3.7.

3.5.2.1 Cast-in-situ reinforced concrete

A distinction is made between six subtypes of cast-in-situ reinforced concrete structures, namely frame structures (RC1), wall structures (RC2), dual systems (RC3), and flat-slab structures (RC4), as briefly described below:

Frame (RC1)

The structural system of reinforced concrete (RC) frame structure consists of beams and columns which form a frame and which are coupled by moment- and shear-resistant beam-column-joints. RC frame structures resist both vertical and lateral forces.

The behaviour of RC frames is determined by the size, stiffness, ductility and strength of columns and beams. Weak columns and strong beams indicate a more vulnerable system against horizontal shaking. In most cases, the structural system can be described as RC frame with masonry infills. The possible interaction between RC frame and brittle infills can contribute to a more vulnerable system. Non-structural infill materials, such as lightweight concrete blocks, hollow terracotta blocks or other perforated bricks are typically not designed to provide lateral stiffening of the frame.

Infills are built between the columns, which are often designed to have the same thickness as the walls, in which case they will have a stiffening effect on the frame even though this is not allowed for in the design. Because of this interaction columns and joints have to resist to additional forces for which they are not designed for. In other cases, the infills are either built partially or fully separated from the concrete frame, depending on the floor plan, or constructed only over a part of the story height, which can create weakness.

RC frame structures are very common and widespread, but this is the building type with the largest scatter of earthquake resistance. In some cases, the vulnerability is comparable to adobe or simple-stone buildings. One might overestimate intensity if the vulnerability class is simply taken for the most likely class from the Vulnerability Table neglecting the probable range and exceptional cases.

For RC frames as well as steel and timber frames, ERD is associated with ensuring a ductile damage pattern (e.g., damage in beam-end regions also known as plastic-hinge regions). Damage and shear failure in columns or in the beam-column joints should be avoided; their occurrence indicates non-compliance with ERD rules.

For RC frame buildings vulnerability classes B to C are probable, with C being most likely. For buildings with serious defects (such as soft storeys, weak columns, lack of stiffening elements like interacting masonry infills or shear walls) vulnerability class B or even A may be appropriate.

For regular RC frame buildings without specific ERD incorporating a certain level of lateral resistance (due to wind forces or common material-specific code design and stability verifications) vulnerability class D might be representative of exceptional cases (refer to 3.7.2.3). Failure of RC frame buildings often leads to major damage cases. Damage observed during past earthquakes provides evidence about typical design defects and reasons for the repeatedly reported damage pattern.

If infills have openings or other discontinuities, a "short-column" effect is predetermined, resulting in brittle shear failure of columns (diagonal cracks with buckling of main column reinforcement). This is a clear indication of a more vulnerable building, where one should assume that a code-consistent level of ERD is not realised by design and/or construction. Considering the actual level of ERD, a vulnerability class has to be assigned below the most likely one (refer to section 3.7).

The seismic vulnerability of RC frames is affected by all the factors previously mentioned like regularity, quality of workmanship or ductility. RC frames are particular vulnerable against severe changes of stiffness over the building height, which might contribute to a horizontally "soft" ground floor with lower horizontal resistance than upper floors, with excessive horizontal drift, which often result in the collapse of the entire building. Such buildings are very vulnerable against lateral forces. If the building has irregularities in the ground plan, the damage will be concentrated at places with the furthest distance from the stiffness centre, e.g., if exterior columns are damaged, this should be taken as an indication of torsional effects and a vulnerable frame. All these described effects and damage patterns should be considered when assigning the vulnerability class.

If the concrete cover is detached, one should perhaps check the confinement provided by transverse reinforcements in the critical end zones of beams and columns to detect the inherent design features, which help to assign the final level of ERD (refer to section 3.7.3). Some guidance is given by examples of the local damage in Figs. 4-40 and 4-45.

- Examples for RC1: Figs. 4-33 to 4-37.
- Examples for RC1-M: Figs. 4-38 to 4-45.

Wall (RC2)
RC wall structures are characterised by continuous vertical walls with elongated cross-section. The walls carry both vertical and lateral forces and should be continuous throughout the building's height. After a strong earthquake, special attention should be given to detached concrete cover and the reinforcement of the wall end zones, and adjacent to door or window openings.

RC wall structures are characterised by a higher horizontal stiffness than RC frame structures. If walls are not placed regularly, and at all outer sides of a building, torsional effects can contribute to partial failure of the entire system. Irregularities in plan or internal setbacks should be considered as serious defects which might contribute to exceptional cases of vulnerability. In addition, the vulnerability is affected by large openings and discontinuities of walls and their geometrical shape over the building height. If two or more walls are connected in a regular pattern by horizontal coupling beams the structural systems can be regarded as a coupled wall structure, where beams should provide sufficient ductility and are intended to be the places of energy dissipation according to recent ERD principles.

RC walls tend to behave within a smaller range of vulnerability classes than RC frame structures. For RC wall structures without ERD vulnerability classes C to D are probable, with C being the most likely one. For RC walls with serious defects a vulnerability class B could be regarded as the exceptional case. One should notice that defects will not lead to as drastic decrease of vulnerability as RC frame structures. According to the Vulnerability Table exceptional cases are restricted to the vulnerability class B and vulnerability class C for walls with ERD. Failure modes and reinforcement details of RC walls indicate their construction quality and level of ERD (refer to section 4.3).

- Example for RC2-M: Fig. 4-46.
- Examples for RC2-H: Figs. 4-47 and 4-48.

Dual system (RC3)
Dual systems are a combination of walls and frames, in which the beams are linked to the walls as well as to the columns as in frame constructions. It is not always straightforward to recognise RC wall or dual-system buildings in the field as in many respects they are similar to RC frame buildings. The presence of large walls without openings on one side of the building may be an indicator, and openings are generally smaller than in frame buildings.

- Example for RC3-M: Fig. 4-49.

Flat slab (RC4)
Flat-slab systems do not have beams and girders, and the loads are transferred directly from the slab to the supporting RC columns, i.e., the beams are integrated into the slab, and of the same depth. The RC flat slab is a two-way slab (solid or waffle), with constant thickness or with drop panels, supported directly on columns with or without capitals or on walls. Edge beams at the slab perimeter may contribute to a framing effect and short cantilever slabs might

improve the seismic response. The most likely assignment is VC B or C; the ranges of vulnerability classes are depending on the quality of construction.

- Examples for RC4: Figs. 4-50 to 4-52.

3.5.2.2 Precast reinforced concrete

A distinction is made between two subtypes of precast concrete structures, namely frame (RC5), and precast wall or dual system (RC6), as briefly described below:

Frame (RC5)

Precast concrete frames are commonly applied as hall-type system to commercial or industrial buildings and in use for storage, shopping centres or production purposes. In general, these building are not suitable for macroseismic damage interpretation. As emphasised in section 4.2, those damage cases can provide valuable (additional) information concerning the level of shaking effects and the intensity assignment, in particular if no other building types are available in the area of consideration.

Precast beams and columns of precast (moment-resisting) concrete frames may be connected by cast in place concrete zones or by other types of joints, which should conform to the detailing for local ductility as for cast-in-situ ones.

- Examples for RC5: Figs. 4-53 and 4-54.

Wall or dual system (RC6)

Buildings constructed with precast concrete elements use stitching or welding to create reinforcement continuity. Precast concrete wall buildings exhibit seismic resistance due to their 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 force path is complete, allowing for an effective transfer of forces to the foundation.

Walls, made of precast concrete panels connected along their edges, should be designed to behave as cast in situ walls. 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 higher vulnerability. Quite common are so called large-panel structures, which were constructed in places such as Eastern European countries and former Republics of the Soviet Union.

- Examples for RC6: Figs. 4-55 and 4-56.

3.5.3 Steel frame (S)

Steel-frame structures are characterised by frames of interconnected steel columns and beams as the lateral force-resisting system. The latter is often supported by diagonal bracing elements. Steel structures usually have exterior non-structural walls (curtain walls) which can be of different materials, including: brick, concrete, lightweight cladding such as metal panels, glass. The floors and roof can be concrete slabs or a metal deck with concrete fill.

Structural damage may, however, be masked by non-structural elements such as cladding or curtain walls, or concrete additions provided for increased fire resistance in composite systems. In such cases, the damage to the joints of the frame will be visible only after the concrete cover has been removed.

The decision on the level of earthquake resistance, and therefore on the most appropriate vulnerability class, should consider the stiffening system as well as the type of joint connections and the presence of interacting infills. The ductility of the entire system is determined by the lateral force-resisting system. This is a valuable indicator for the appropriate vulnerability class:

For steel-frame buildings without special measures of ERD, the probable vulnerability class is D. Bracings that affects columns (K-bracing) gives less earthquake resistance, and should be represented by vulnerability class C. In most cases, moment-resisting frames, frames with RC walls, frames with X- or V-bracing provide lateral resistance and ensure a ductile behaviour. The probable vulnerability class is D to E.

Eccentric bracings are typical measures to improve seismic resistance corresponding to moderate or high level of ERD. Vulnerability class E can be considered as the most likely vulnerability class. As for RC buildings, the vulnerability class depends on the level of ERD. The impact of code practice and seismicity on the level of ERD are discussed in section 3.7. Only in a few countries, steel construction is used for residential buildings. Commercial or industrial buildings are usually diverse and therefore poor indicators of damage levels.

- Examples for S: Figs. 4-57 and 4-58.
- Example for S-M/H: Fig. 4-59.

3.5.4 Timber (T)

The inherent flexibility and horizontal deformation capacity of timber (or wooden) constructions give timber buildings a high seismic resistance. However, this can vary depending on the construction method. A distinction is therefore made between non-engineered traditional construction (T1) and engineered construction using a frame or wall (T2).

3.5.4.1 Traditional (T1)

Timber construction has been used traditionally in many countries; timber elements are often applied to adobe structures improving the earthquake resistance (refer to section 3.5.1.2). The variety of traditional methods includes post and beam construction (e.g., *Wattle and Daub,* half-timbered, *Colombage* in France, *Fachwerk* in Germany and neighbouring regions), *Shinkabe/Okabe* in Japan, *Himiş and Bağdadi* in Turkey, *Dhajji Dewari* in Kashmir, India, lightweight timber frame in tropical regions and pole structures covered with thatch or mud-plastered walls of bamboo or reeds (*Bahareque,* refer to Fig. 4-60, in Central and South America, also known as *Taquezal* in Nicaragua, *Quincha* in Panama, Bolivia and Peru, *Tejamanil* in the Dominican Republic), and *Sinsh* in Central Asia. Other regional denotations exist. They might be explained within National Annexes in more detail (refer to section 3.9).

These forms of construction have demonstrated a superior performance in earthquakes compared with local forms of unreinforced masonry or reinforced concrete. Noteworthy examples here include constructions in parts of Southern Europe, i.e., a dual system of stone masonry and timber frame in the form of the *Casa Baraccata* (in Southern Italy) and *Pontelarisma* (on the Ionian Island Lefkada).

Houses with timber frames possess added strength and perform significantly better. Such buildings may suffer damage to the infills relatively easily, while the framing elements remain mostly intact. One also encounters cases where unconnected wooden beams and columns are used in adobe houses; these provide extra horizontal stiffness and therefore improve resistance, but not so much as a connected frame would do.

These types of timber structure may be typically represented by vulnerability classes C or D. Despite the fact that, these types are resistant against lateral forces, they should be distinguished from (engineered) timber-frame structures, in particular those following specific design rules. Therefore, the structural system providing lateral resistance should be considered carefully. Loose joints or rotten wood can make a wooden house quite vulnerable to collapse.

Timber is also, more rarely, used as heavy log and wood panel construction. Wherever timber is available it is also used for non-residential buildings, commercial and agricultural buildings and warehouses, using a variety of building techniques.

- Example for T1: Fig. 4-60.

3.5.4.2 Frame or wall (T2)

The majority of engineered systems can be regarded as light timber frames (if an efficient framing action can be attested). If the beam and columns are connected by nailed plates (of gypsum and other brittle materials) or if these connections are weak the structure will fail if connections fail. The level of ERD of timber structures depends on the ductility of the connections.

A typical modern timber stud-wall building is resting on a RC strip foundation, on which the timber ground floor is constructed and anchored to the foundation. The ground floor consists of a platform of softwood timber joists covered with a deck of plywood or other timber-based board. On this platform, exterior and interior ground floor walls are built, consisting of a timber sill plate and regularly spaced vertical timber studs of a suitable width, and with board or panel sheathing nailed to the studs on the outside of the building. The studs are capped with a double header plate and the first floor is built on this, in turn acting as a platform for the upper floor walls, on which a roof of timber rafters or prefabricated trusses is built and covered with tiles or roof sheets. An external cladding of brickwork or of horizontal timber boarding may also be used.

In older houses of this type, inadequate connection of the ground floor to its foundation can lead to a detachment of the building from its foundations, resulting serious damage to water, electricity and gas connections. Older buildings may also lack adequate shear resistance through sheathing boards which are either inadequate in size, not continuous, or insufficiently connected to the vertical studs. In older buildings the timber may be of poor quality, and may suffer from rot, fungal attack or insect attack, especially if the timber is not treated; and metallic connections may suffer from corrosion. All of these factors can significantly increase the vulnerability of the building. In addition, heavy roofs (needed for typhoon resistance), coupled with inadequate bracing contribute to higher vulnerability.

Improvements could be made in the future to the way in which timber structures are handled by the scale. Such improvements include more refined or different subdivision of the structural types, and addressing in detail the stages of damage to timber buildings which are not described in the definitions of damage grades in the scale in the way that they are for adobe, brick masonry and RC structures. In this context, recent code development and included construction might be considered. An evaluation of their vulnerability can follow the assumed quality of earthquake response which is expressed in ductility, structural response or behaviour factors.

Log cabins or blockhouses are widespread in regions with natural wood resources (refer to Fig. 4-61). They are known for their resistance, global stability and good performance under earthquake action; vulnerability class E (or F) can be expected, being typical for Type T2-M/H. Consequently, no damage cases are reported, and for statistical elaboration the data base is limited.

Observations from modern timber buildings require a systematic evaluation of the damage pattern on the basis of well-defined subdivision of structural systems. On the other hand, the identification of structural system might be problematic if the (light) timber framing is covered by an external masonry facade (brick, concrete blocks) and the damage of the timber elements only becomes visible after the partial failure of this brittle shell.

- Examples T2: Figs. 4-61 to 4-65.
- Examples T2-M/H: Figs. 4-66 and 4-67.

3.5.5 Other building types, not listed in the Vulnerability Table

If the structural system is unclear, i.e., composed of different materials and structural systems (also between the stories) and, therefore, is not satisfying the rules for a regular building following the basic requirements (uniformity, symmetry, simplicity), the building should not be considered for intensity assignment.

The vulnerability of composite or "mixed" structures has to be assigned by focusing on the predominant horizontal structural system and to follow the worse ranges of the two types (unless exceptional cases). If the building (adobe, masonry or timber) is resting on a rigid basement, the assignment of the type of structure should refer to the building part above the rigid basement (refer to Fig. 4-61).

For modern composite steel-concrete buildings moderate to high level of ERD can be expected. It was decided to not integrate this construction type into the Vulnerability Table. Non-engineered buildings of informal settlements are so far excluded from any vulnerability assignment. They should not be regarded as "structural" systems.

3.6 Factors affecting the seismic vulnerability of buildings

There are a number of factors that affect the overall vulnerability of a structure besides construction type. These factors are generally applicable to all types of structures, both engineered and non-engineered as well as structures with and without ERD. These can be used to shift the final vulnerability class from the most likely class to a different one, within the range shown by the Vulnerability Table. The discussion here is an overview of the different factors. ERD is discussed further in the next subsection.

3.6.1 Quality and workmanship

It must seem common-sense to say that a building which is well-built will be more resistant than one that is badly built. The use of good quality materials and adequate construction techniques can result in a building much better able to withstand shaking than the use of poor materials and slipshod workmanship. In the case of masonry, the quality of the mortar is particularly important, and even rubble masonry can produce a reasonably resistant building if the mortar is of high quality. Poor workmanship can include both carelessness and cost-cutting measures, such as a failure to tie in properly parts of the structure. In cases of poorly built engineered structures, it may be that the finished structure fails to meet the provisions of the appropriate seismic building code.

3.6.2 State of preservation

A building which has been well-maintained will perform in accordance with its expected resistance from other factors. A building which has been allowed to decay may be significantly weaker, sufficiently to reduce it by at least one vulnerability class. This may be observed in cases of abandoned or derelict buildings, and also in cases where there is an evident lack of maintenance. A case particularly to be mentioned is that of buildings already damaged (most commonly by a previous earthquake, where one is dealing with a series of shocks). Such buildings can behave very poorly indeed, so that a relatively weak aftershock can cause disproportionate amounts of damage (including collapse) amongst buildings damaged by the main shock.

One should note that a building may appear to be in good condition because attention has been given to maintaining the aesthetic appearance of the building only, i.e., fresh plaster and nice paint do not necessarily mean that the structural system of the building is also in sufficient repair.

3.6.3 Regularity

From the point of view of earthquake resistance, the ideal building would be a cube in which all internal variations in stiffness (like stairwells) were symmetrically arranged. Since such buildings would be impaired functionally and deplored aesthetically, one may expect greater or lesser variations from this perfect plan in most buildings one encounters. The greater the departure from regularity or symmetry, the greater the vulnerability of the building to earthquake shaking, and it is often possible to observe in damaged buildings how the irregularity has clearly contributed to the damage (e.g., in the collapse of soft storeys).

Gross irregularity is easy to identify; for example, buildings with ground plans designed as an L shape or similar are often encountered and are subject to torsional effects which may greatly increase the damage suffered. It would be unwise to assume that a building meets standards of regularity solely on the grounds of possessing symmetry in its external dimensions. Even if the ground plan is regular, problems may arise in buildings which have marked asymmetry in the arrangement of internal components of varying stiffness. The position of lift shafts and stair wells is often noted in this respect.

One often encounters cases of buildings in which one storey (usually the lowest) is significantly weaker than the others; often it may be quite open, with columns supporting the upper storeys but no walls. Such cases are known as soft storeys and are highly prone to damage and even collapse in an earthquake. Continuous strips of window over the length of the building may introduce similar effects.

In some cases, buildings that previously had a good level of regularity may be adversely affected by subsequent modifications. For example, conversion of the ground floor of a building into a garage or shop may weaken it (creating a soft storey). Building on an extension to a building is likely to make the ground plan more irregular and introduce irregularities of stiffness and period within the overall structure. Old masonry buildings may have been extensively modified over a long history, resulting in offsets of floors at different levels, foundations at different levels on a slope, and so on.

3.6.4 Position

The position of a building with respect to neighbouring buildings can affect its seismic behaviour. In the case of a row of houses in an urban block, it is often those houses at the end of a row or in a corner position that are worst affected. One side of the house is anchored to a neighbour while the other is not, causing an irregularity in the overall stiffness of the structure which will lead to increased damage. Severe damage can be the result of two tall buildings of different fundamental periods that are situated too close to one another. During an earthquake they may sway at different frequencies and smash into each other, causing an effect known as pounding. Such damage is not a measure of the severity of earthquake shaking as such and should be discounted in assigning intensity.

3.6.5 Use of damage information

In macroseismic surveys, in cases where the vulnerability class is increased from the most likely class by one or more classes on the basis of observed damage in a particular location, a corresponding change in vulnerability class should be considered where the same building type occurs in other locations (whether damaged or not). It can be the case that an earthquake affects an area of similar structures, which can be damaged to a greater or lesser degree. In which case, weaknesses or strengths may be more visible in those structures suffering worse damage, which can be inferred also to exist in the less damaged buildings of the same type, such that the assessment of vulnerability class is correspondingly affected.

3.6.6 Retrofitting

Where measures have been taken to retrofit buildings to improve them against earthquakes, the effect is to create what are practically new, compound and resistant building types. These can differ radically in performance from the basic, unmodified building. For example, taking old field-stone constructions and improving the horizontal elements by replacing the floors or inserting ties can substantially improve the performance. If in addition to this, mortar or epoxy injections or RC jacketing is applied, the performance can improve further.

3.6.7 Regional considerations

To some extent all the above, and ERD also, can be related to regions in a general way. For any country, one can consider first: is it exposed to high or low seismicity? And second: does it exhibit a high or low level of earthquake awareness? In countries with generally low awareness of earthquake risk, one can expect generally poorer standards of earthquake resistance. If, in addition, the seismicity is low, there may be really no motivation for earthquake resistance to be considered. On the other hand, in countries where there is an obvious risk from strong winds, structures may be proof against lateral loading for other reasons.

3.7 Earthquake-Resistant Design (ERD)

This section is intended to provide some general overview on the classification of engineered buildings, reflecting the development as well as differences and refinements within different generations of national seismic building codes. Particularly for the purpose of a macroseismic scale, it can be difficult to give a condensed overview of the topic, given it is a complex subject and requires engineering expertise. What follows is therefore a simplified overview, and by no means a technical manual.

Correlations between levels of earthquake resistance according to seismic codes and typical vulnerability classes provided in IMS have had to be developed; this required an interchange between national specialists. As the number of observations is limited, and the re-interpretation of damage cases might cause legal implications, damage curves or vulnerability functions (refer to 3.3.2) for different types of engineered structures may provide insight into the intended and actual level of ERD. These levels can differ between different countries. They are also non-uniform with respect to the level and the aims of national earthquake regulations, and may change with time. For macroseismic interpretation and classification of the shaking effects, the actual vulnerability classes will need to be assigned with respect to the actual level of ERD, which may differ from that stipulated by the appropriate building code due to a variety of reasons.

3.7.1 Building Codes

The essence of ERD is that building design can be supported by the application of building codes and regulations. Such rules have been established on the basis of experience and observations of how simple measures can improve the response of buildings and thus avoid collapse. Historically, this was an informal process; today more formal codes and regulations now exist for each type of structure, and, in general, these design principles need to be evaluated to ascertain the level of earthquake resistance in terms of vulnerability. As it is not straightforward to identify the level of ERD from field observation, one is largely reliant on ascertaining the level on the basis of the building code under which a building was constructed, with possible modifying factors.

Substantial research, reflecting the lessons learned over time from the effects of significant earthquakes, has resulted in the evolution of seismic codes and these lessons have influenced construction practices in earthquake-prone areas. However, in regions where earthquakes are less frequent yet destructive, adherence to codes tends to be relaxed with time, until a new seismic event occurs again.

The development and adaptation of seismic codes are influenced by various factors, including direct experience with seismic events, the influence of neighbouring more developed countries, increased national wealth and a corresponding decrease in risk tolerance, ongoing advancements in research related to seismicity and not least, historical colonial influences. As codes develop over time, the level of ERD should improve at each stage, and one can distinguish between pre-code construction, when structures were designed for gravity and wind loading, only, early code, and more sophisticated levels of modern and recent code generation.

3.7.2 Code-consistent level of ERD

3.7.2.1 Level of seismic hazard

The code-consistent level of ERD has to be considered in relation to the level of seismic hazard of a specific area. These levels of seismicity, or more precisely these levels of expected ground shaking are provided in national zoning maps in terms of intensity measures like peak ground acceleration (PGA) or a set of spectral accelerations for a 10 % probability of exceedance in 50 years, corresponding to a 475-year mean return period. Although definitions of the ranges for low, moderate, and high levels of seismic hazard may vary, the parameters given in Table 3-1 can be used for orientation.

3.7.2.2 Basics of earthquake-resistant structures

Damage interpretation requires an understanding of the structural system which determine the response under earthquake shaking in the ground and the corresponding cyclic loading conditions. The following main characteristics can be distinguished:

Strength is related to main structural system and its force-resisting elements and their ability to respond mainly in a material's elastic or elastic-plastic range against forces. Visible indicators are the geometrical parameters (size of cross section). High strength means limited deformations, i.e., higher stiffness, and probably less damage.

Stiffness is related to structural system and its force-resisting elements, the interaction with non-structural parts (like infills, claddings) and the ability to respond by more or less limited extent of deflections or drifts.

Global stability refers to the ability of the whole building to collapse if individual elements suffer damage or fail locally, and to maintain the force transfer without the danger of collapse. The re-activation of such internal redistributions of force-bearing capacities is often referred to as *redundancy*.

Horizontal deformation capacity refers to the ability of the elements or stories of a structural system to withstand horizontal seismic action without failure following design and response requirements (for different intensities).

Ductility is a to-be-defined measure of a building's ability to resist lateral forces in a post-elastic range, i.e., by dissipating seismic energy and allowing damage in a controlled wide-spread or locally concentrated manner, depending on the type of construction and structural system. Ductility is used in codes to account for the total horizontal deformation capacity relative to the elastic horizontal deformation and is quantified for the type of construction material and structural system.

In correspondence with the international code development, the level of ductility, expressed in ductility classes, helps to distinguish and anticipate the building's ability to withstand seismic action in a post-elastic range and to assign the level of ERD. In principle, a building with a high-level of ERD is expected to have a high ductility class to provide larger safety margins against undesirable higher damage grades.

All the mentioned properties and characteristics contribute to the response and performance of a building in case of an earthquake and intensity measures which might be lower or higher than the design parameters.

3.7.2.3 Code generation and the level of ERD

The design level is closely linked to the differentiation of code generations (refer to Table 3-1) and design principles that were requested and applied at the time of construction of respective buildings. The following code generations can be distinguished:

Pre-code refers to buildings built before any ERD code was in use, i.e., structures were designed for gravity and wind loading, only.

Early code refers to codes which specify seismic forces, but do not incorporate any provisions for the ductile detailing of the structural components and connections (typically referring to codes in practice prior to the 1980s). Commonly, in pre- or early code generations, buildings were designed for a base shear coefficient of 2 - 4 % g, 5 - 7 % g or 8 - 12 % g in regions of low, moderate or high level of seismic hazard.

Modern code refers to codes which specify seismic forces usually in the form of a design response spectrum and also incorporate ductile detailing requirements.

High code refers to the recent code generation, where performance-based design principles and target responses are implemented.

The level of ERD can be distinguished on the basis of design parameters for the target site and the relevant code generation. Thus, it is possible to predict the code-consistent ERD level and thus evaluate the ERD type(s) of engineered buildings in the study area based on the level of seismic hazard specified in the national seismic building code.

Table 3-1 Guidance in the assignment of the code-consistent level of ERD

<table>
<tr><th rowspan="3">Level of seismic hazard
(in terms of PGA or $S_{a,\alpha}$ for the 475-year return period)</th><th colspan="7">Code generation</th></tr>
<tr><th colspan="2">pre</th><th colspan="2">early</th><th colspan="2">modern</th><th>high</th></tr>
<tr><td colspan="2">Typically intro-duced after [1950]</td><td colspan="2">Typically intro-duced after [1980]</td><td colspan="2">Typically intro-duced after [2000]</td><td>Typically introduced after [2020]</td></tr>
<tr><td>Low
PGA ≤ 0.1 g
$S_{a,\alpha}$ ≤ 0.25 g</td><td colspan="3">N.A.</td><td colspan="4">ERD-L</td></tr>
<tr><td>Moderate
0.1 g < PGA ≤ 0.2 g
0.25 g < $S_{a,\alpha}$ ≤ 0.5 g</td><td>N.A.</td><td colspan="2">ERD-L</td><td colspan="4">ERD-M</td></tr>
<tr><td>High
PGA > 0.2 g
$S_{a,\alpha}$ > 0.5 g</td><td colspan="2">ERD-L</td><td colspan="3">ERD-M</td><td colspan="2">ERD-H</td></tr>
</table>

PGA: Peak Ground acceleration

$S_{a,\alpha}$: Horizontal spectral acceleration in the plateau of the elastic response spectrum for rock sites and for 5% damping, for modern and high code generations.

Explanations to Table 3-1 and the recommended choice of vulnerability class (VC)**:**

[Year]	Values in brackets are approximate and can differ according to the code history in respective countries.
N.A.	**N**o **A**ssignment; ERD should be justified on the basis of national code development [As per type of structure].
ERD-L	[As per type of structure]: *most likely* VC is recommended; vulnerability affecting factors have to be checked.
ERD-M	[As per type of structure] with moderate level of ERD: *most likely* VC is recommended.
ERD-H	[As per type of structure] with high level of ERD: *most likely* VC is recommended.

Under the assumption that codes have actually been correctly applied, the code-consistent level of ERD type can be assigned for engineered buildings. For assigning the code generation, the year of code application might provide the entry (refer to Table 3-1).

The level of ERD is expected to be relatively uniform within any earthquake region for which intensity has to be assigned. The level can be non-uniform when buildings within an earthquake region have been designed for different codes, for example, where an old code has been updated or replaced entirely by a new one.

Engineered buildings with modern structural systems, not designed against lateral seismic forces, can still provide a certain level of earthquake resistance which can be comparable to the level incorporated in engineered buildings with ERD. Also, structures designed against high levels of wind loading can be regarded as having some inherent earthquake resistance.

Well-built (non-engineered) timber or masonry structures can behave in a fashion comparable to buildings with ERD. This may also concern buildings to which special improvements have been applied. In such cases, even field stone structures can behave well above their normal, reaching the vulnerability class of exceptional cases.

Whereas the various ERD levels have already been mentioned above, including specifications in Table 3-1, the ERD levels can be defined for the purposes of the scale as follows:

ERD-L: Engineered buildings incorporating a *low level of ERD*

In an ascending ranking of design features, buildings with minimal or rather uncertain ERD are at the lowest level. Such buildings may include RC, steel or timber buildings as well as masonry constructions, designed by structural standards without consideration of seismic action. Engineered buildings of this type are typically the case in regions of low seismicity where earthquake design regulations are non-existent or are present only as recommendations. In general, ERD-L refers to pre- and early code generation building, that lack adequate features compared to the current state of practice. This level includes general rules for structural parameters, is still the dominant one and is widespread in areas of low or moderate levels of seismic hazard.

Accounting for the impact of material code application itself, reinforced concrete, steel and timber structures without special ERD – classified here as ERD-L – refer in the Vulnerability Table to the type of a structure, only. The typical vulnerability class for this type is C for reinforced concrete (RC) and D for steel and timber.

ERD-M: Engineered buildings incorporating a *moderate level of ERD*

At this level are buildings with ERD, i.e., buildings designed and built according to the scope of seismic codes. A set of advanced design principles has been followed, including state-of-the-art methods of seismic hazard assessment. Buildings of this type can be expected in regions of moderate level of seismic hazard where the design of buildings must consider ERD regulations. This level is characterised by the realisation of design rules. Special measures of detailing to improve ductility and deformation capacity are implemented. Practice may vary between early codes and modern ones.

ERD-H: Engineered buildings incorporating a *high level of ERD*

Special measures of detailing are provided to ensure a ductile system where the seismic energy is distributed all over the structure and is mainly dissipated in plastic hinges without structural failure. This type should be expected in areas of high level of seismic hazard.

This level should be characterised by improved ductility of structural systems and controlled mechanisms of damage progression as a result of special design features. Particularly, for steel and timber structures, buildings with moderate and high level of ERD are grouped together here in a single type. At present, observations do not allow further refinement, and no relevant difference in the observable damage should be expected for earthquakes where the intensity measures correspond to the level of the design earthquake.

At the highest level one also finds buildings with special anti-seismic devices, such as base isolation. They behave in a special manner, typically avoiding damage unless the base isolation process fails in some particular way, and cannot be used for intensity assignment at all.

3.7.2.4 Importance

Buildings are classified code-consistent into different consequence classes, often expressed by importance categories. The importance of a building is determined by the number of occupants or visitors, the use of the building (or the consequences of interruption of the use), or the danger for public and environment in the case of the building's failure. In general, specific performance requirements should be satisfied.

High consequence classes refer to buildings of vital importance for civil protection (e.g., hospitals, fire stations, and their equipment), and buildings which should remain operational at all times (e.g., communication and data centres, including their equipment), and also to buildings whose seismic resistance is of importance in view of the consequences associated with a collapse (e.g., schools, assembly halls, cultural institutions).

For engineered buildings, this aspect has to be taken into account because it contributes to different design levels and required performance for the same type of structure. The performance requirements refer to the state of damage of the structure and are described through Limit States by the code.

The classification of consequence classes or importance categories is widely harmonised in national earthquake regulations and is linked to the definition of importance or performance factors amplifying seismic action. As a consequence, buildings of higher importance are designed for forces corresponding to higher levels of seismic hazard and mean return periods.

3.7.3 Real level of ERD

After having determined the code-consistent level of ERD, it is necessary to identify in a second step the final, really implemented level of ERD and to assign the vulnerability class. This involves consideration of regularity as well as of the quality of workmanship of the different types of structure. In addition, it is necessary to compare the design levels of engineered structures in the earthquake region with the idealised characteristics of ERD types expressed in terms of hazard related design coefficients or intensity measures.

It has to be expected, that the user of the scale is to a certain extent informed about the construction practice and the realised quality of structures. Not least, the observed global and local damage can help to decide whether a code has been fully implemented or whether the real level is below the code-consistent level. In many cases, it has to be assumed that the code has not been properly implemented and that the real level is lower than the code-consistent one. Conversely, the level may in some cases be higher for buildings of higher importance or for special structures (refer to section 3.7.2.4). The damage examples of section 4.3 for RC (Figs. 4-33 to 4-56), steel (Figs. 4-57 to 4-59) and timber (Figs. 4-61 and 4-67) indicate the most appropriate, estimated level of ERD.

3.7.4 Assignment of vulnerability class

Vulnerability classes for different types of structures should be evaluated for engineered buildings primarily based on the intended (code-consistent) level of ERD. These levels can differ between countries. They are also non-uniform with respect to the level and the aims of national earthquake regulations and may change with time in any country or region. The actual vulnerability class will be assigned with respect to the real level of ERD, which may differ from the code-consistent level, due to other factors.

The range of probable vulnerability classes in the Vulnerability Table is more or less an indicator of the vulnerability contributing factors and the level of ERD provided. Starting from the code-consistent level, which should correspond to the most likely vulnerability class, the user has to decide on the real level. If design deficiencies become apparent, the assignment of less probable lower VC may be appropriate. Vulnerability classes higher than C or D are practically restricted to engineered buildings with a certain level of ERD or to well-constructed timber structures.

3.7.5 Particularities of damage

Particularities of observed damage should be recognised. For this purpose, damage examples in section 4 for different types of structures show the global as well the local damage and details of construction indicating the presence or neglect of ERD principles. Structures with moderate or high level of ERD will respond in an intended controlled way of non-linear energy dissipation, i.e., damage is an inherent part of modern design concepts.

An important element of designing a building against earthquake shaking is to identify those areas where damage is permitted; these parts of the building will dissipate the shaking energy without prejudice to the structure as a whole, thus preventing the structure from more severe damage or collapse. This principle is known as capacity-based design that focuses on the appropriate failure mechanism of a structure by ensuring that certain components, like beams, yield while others, like columns, remain elastic to prevent critical damage during seismic shaking. The investigator will therefore need to pay attention to these critical zones, assuming that details of reinforcement or the quality of joints and connections have become visible after the earthquake (refer to example illustrations in section 4.3).

The percentage of buildings with a certain level of ERD is steadily increasing. The situation becomes more complex when buildings are divided between different generations of building codes because these affect the response to shaking in different ways. A major challenge for evaluation arises from the question as to whether ERD can be detected visually by an investigator who is not an expert in engineering. Also, is the level of ERD visible before or only after a damaging earthquake? After the event it becomes easier and more helpful because the defects become visible in the form of failure and in the exposed details of structural layout or construction.

Also, in the field, the question arises: "How can the user decide that a building is code-compliant or not?" This is challenging and requires support. ERD means that the suitable members of the structural system are chosen, designed and detailed for energy dissipation under severe deformation. As long as all other structural members are provided with sufficient strength, only minor or no damage should be visible there.

It also challenging to interpret damage to RC, steel and timber structures concerning the level of ERD as observations are rather limited and can often only be based on analytical studies. Nevertheless, it can be stated that any building with moderate or high level of ERD has the following major qualities: In the case of the occurrence of the design earthquake as defined by the code, not just a few, but many zones of the structure – those predetermined and selected for energy dissipation – will have local damage. The required deformation capacity should result from damage distribution over the whole height of the building, and not from damage concentration in single (often soft) storeys.

3.8 Remarks on introducing new types of structure

It is not possible to cover all building types worldwide within the scope of the guidelines of this scale. At least the Vulnerability Table covers the major types. The following brief instructions provide some indications to how to add new types. This is unlikely to be a straightforward procedure and can be 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 building type with those already covered and attempt to establish an equivalence. If it is considered that the type is as resistant, than normal masonry construction, as an example, then one may classify the type as being basically of vulnerability class B. If the type is such that, owing to innate deformation capacity, it never performs worse than masonry buildings, but in some cases it performs significantly better, then one might deduce that the building type should be represented on the Vulnerability Table as a circle under vulnerability class 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 masonry 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.

3.9 National Annexes to IMS-25

The recommended approach to the question of new building types of local importance in different parts of the world is the concept of National Annexes. National Annexes would be documents written to facilitate macroseismic studies in parts of the world where one has to deal with typical building types not common elsewhere and not described in section 3.4 and the Vulnerability Table and the example illustrations (chapter 4).

Such a document should be prepared by local experts familiar with typical buildings in their national territory, and the behaviour of these buildings under earthquake loading. It should contain descriptions of any typical building type of an individual character, preferably with photographs illustrating the building type in an undamaged and damaged state.

Also needed are descriptions of characteristic damage states, remarks on the probable vulnerability class, and mention of common features likely to affect vulnerability class; for instance, whether the use of substandard building materials is a common problem.

Some general qualifications of National Annexes could be:

- A National Annexe is not an official part of the International Macroseismic Scale.
- The intellectual property rights (IPR) of a National Annexe reside with the authors of the National Annexe. The IPR of IMS-25 reside with the scale's authors.
- Language, format and translation of a National Annexe are at the discretion of the authors of the Annexe.
- A National Annexe would not contradict any part of IMS-25, in particular, for the ranges of vulnerability classes.
- A National Annexe may introduce additional building types relevant to a country or region which are not in IMS-25, with appropriate descriptions of the type of structure, and appropriate definitions of the expected and possible ranges of vulnerability class, and with suitable generalised and/or photographic illustrations of damage grades; refer to Table "Classification of damage to buildings of traditional timber" and Fig. 4-60.

Aside from these considerations, the authors of the National Annexes could prepare and publish it in ways suitable for the intended region.

4 Classification of Damage to Buildings

4.1 Damage description and its schematic drawings

The classification of damage in Part I (the Core Scale) into five damage grades, together with the division of structures into vulnerability classes and the definitions of quantities (few, many, most) form the essential components of the macroseismic scales EMS-98 and IMS-25. An important advance of modern scales is that both a qualitative and quantitative approach to damage description have been introduced; the qualitative aspect deals with the type of building and its vulnerability; the quantitative aspect deals with the relative frequency or shares of different grades of damage occurring at a given intensity (refer to section 3.3.2).

The damage grades represent an increase in the severity of shaking. They do this only approximately and provide descriptions which can be readily distinguished by the (often non- or less-experienced) operator. As in previous scales, it is emphasised that different types of buildings respond and fail in different ways; this fact becomes visible by the different types of damage pattern or failure mechanism. This has been addressed in EMS-98 and is extended now by tables for additional building types in the core part of IMS-25.

Descriptions of damage grades for masonry and RC structures were here taken from EMS-98 with minor modification. As an innovative extension, IMS now contains description of damage grades for the other building types and their structural and non-structural elements. Damage grades for timber structures are given for a type known as half-timbered frame; in fact, there is a large variety of systems and for many there is at present insufficient data to represent accurately the whole range of different behaviours.

Damage grades for steel structures are given in a descriptive way, only. This is partly due to the difficulty of defining a “typical” structure, partly due to the relative lack of a smooth progression of damage to illustrate, and partly because much of the damage is typically to the interior of buildings, and investigating the interior of a damaged building is an unsafe practice.

Due to the variety of systems, bracings, infills and claddings, and accepting the growing number of composite structures, and the minor importance of steel structures compared to other, more vulnerable types of structure for intensity assignment, it was decided to abstain from drawings of a single type, which is not supported by observations for the different damage grades or levels of shaking. As steel construction is seldom used for residential buildings, and then only in few countries, damage cases are likely to be encountered only for commercial or industrial buildings which usually are hall-type structures. They might be indicators for the severity of shaking in comparison to the other observed effects.

The drawings of damage grades illustrate in a simplified way the essential elements within the progression of damage from grade to grade; intended to be understandable also to the non-engineer. Concerning the descriptions of damage grades, the focus is given to the use of quantitative terms: like “few” or “many” cracks, or large cracks in “few” or “many” walls.

With respect to the definition of damage grades in the IMS, one must carefully distinguish between non-structural and structural damage. In the case of RC frame structures, the level of damage to non-structural infills should be compared to the actual damage to the frame elements. This might also indicate the extent of interaction and the level of ERD (section 3.7).

4.2 Examples illustrating the assignment of vulnerability and damage

To support the application use of the IMS, a series of examples illustrate the assignment of vulnerability class and damage grade for typical types of structures. The example illustrations represent an extension to those of the EMS-98. The examples are aimed at guiding users towards a systematic classification of damage grades and the consistent use of the Vulnerability Table, i.e., the identification of the appropriate structural type, as well as the decision on the proper vulnerability class within the given ranges of the Vulnerability Table.

Residential: In any earthquake-affected area one can generally expect the majority of buildings to fall into the residential category, thus these will provide the standard material for intensity assignment. This is particularly important for the use of the IMS, since it relies on the statistics of damage to a population of buildings, and not to single structures. Examples: Figs. 4-1 to 4-38, 4-40 to 4-45, 4-50 to 4-54, 4-57 to 4-67.

High-rise: As recommended in section 1.7, reports from observers higher than the fifth floor should be discounted when assigning intensity. Shaking variations observed at different levels are caused by the dynamic characteristics and become visible in the response of non-structural elements like infills in RC frame structures, refer to Fig. 4-39. More Examples: Figs. 4-46 to 4-49.

Hall type: These structures are often applied for commercial and industrial use, and they may be dominating certain (more external) city regions. Typical is the failure of large vertical panel elements. Examples: Figs. 4-55 and 4-56.

Others: The parking building in Fig. 4-60 is showing the up-grading of a RC frame structure by steel frames with eccentric bracing. The structural system is comparable of that for multi-story residential or commercial buildings. The assignment of VC follows section 3.5.3 and not 3.5.2.

Monumental buildings: The structural and non-structural complexity of such buildings is such that they may be more likely to be damaged than ordinary buildings, even though they may be better built. Such data must therefore be handled with care, as complementary to other evidence - if available. For the use of information from historical records refer to section 2.7.5.

Special structures: Special structures have special structural systems such as shells (tanks, silos) or long-span (bridge) constructions. They are excluded from intensity assignment (refer to section 1.7).

4.3 Collection of example illustrations

Table 4-1 provides an overview of the collection of examples to illustrate the assignment of vulnerability class and damage grade for the masonry types of structure. Table 4.2 is completing the compilation for RC, steel and timber structures. Reference is given to year and name of the earthquake; it is not intended to allocate the city or place of the building in more detail.

The examples are prepared in a catalogue-like tabular form. For different earthquakes and regions, comments on example buildings now describe the choice of the damage grade and the vulnerability class. It must be recognised that in the majority of cases, the examples are provided by the main authors, i.e., are based on a comprehensive knowledge level with respect to the whole spatial damage situation. In other cases, limited knowledge should be addressed carefully, in particular, when the description and assignments are derived from one photo, only. Therefore, the selection of examples follows essential quality criteria, which should determine the standard for further extension or the compilation of National Annexes (refer to section 3.9).

Explanations with respect to the comments given for each example are as follows:

First comments refer to vulnerability affecting parameters and indications which can be taken from the photos, directly. It provides arguments for the building evaluation comparable to field work, and results in the assignment of the vulnerability class. Both, the type of structure and the assigned vulnerability class refer to the Vulnerability Table. The **ranges of vulnerability classes** (most likely, probable, less probable and exceptional cases) are repeated; the **green dot** gives the finally assigned vulnerability class. Material and type of masonry units are mentioned if they are clearly visible.

Second comments give guidance in the evaluation of the damage grade. It has to be distinguished between visible effects in the photos and interpretations in the comments. The decision for the damage grade should be based on the indicators compiled in the tables of the Core Scale for masonry, RC, steel and timber structures.

The user of the scale has to assign a global damage grade mirroring the shaking effects on the whole building. The damage grade includes different observations of the structural system and non-structural elements. In the majority of examples, photos show whenever available two facade views of the building; in some cases, the final decision might require additional information.

The **red dot** represents the result of evaluations considering particularities of all visible effects. The detailed photos are in general separate photos taken from a different angle; in one case (Fig. 4-52) the detailed photo is just zoomed into the main photo.

Table 4-1 Overview of example illustrations in Figs. 4-1 to 4-32 for the assignment of vulnerability class (VC) and damage grade for masonry

Type of Structure		Abbrev.	Year Earthquake	VC	Damage Grade					Fig.
					1	2	3	4	5	
MASONRY	Rubble Stone	M1	2015 Nepal	B			O			4-1
			2023 Nepal	A				O		4-2
			2023 Nepal	B				O		4-3
			1998 Turkey	A					O	4-4
	Field Stone		1995 Greece	B			O			4-5
			2023 Nepal	A				O		4-6
			1995 Greece	B				O		4-7
			1980 Italy	A					O	4-8
	Adobe	M2	1990 Kazakhstan	B		O				4-9
			1986 Moldova	B			O			4-10
			2007 Peru	B			O			4-11
			2010 Chile	B			O			4-12
			2008 Greece	A				O		4-13
			1985 Tajikistan	B				O		4-14
	Simple Stone	M3	1991 Switzerland	B		O				4-15
			1979 Montenegro	B				O		4-16
			2016 Italy	B				O		4-17
	Massive Stone	M4	2012 Italy	C	O					4-18
			1999 Switzerland	C		O				4-19
			2016 Italy	C			O			4-20
			2009 Italy	C				O		4-21
	Manufactured units with timber floors	M5	1978 Germany	B		O				4-22
			1985 Czech Republic	B		O				4-23
			1992 Netherlands	B		O				4-24
			1996 Italy	B		O				4-25
			1976 Italy	B			O			4-26
			1976 Italy	B			O			4-27
			2009 Italy	B			O			4-28
			1979 Montenegro	B				O		4-29
			2016 Italy	C	O					4-30
	Manufactured units with RC floors	M6	1995 Greece	C			O			4-31
	Confined or Reinforced	M7	2015 Nepal	C	O					4-32

Table 4-2 Overview of example illustrations in Figs. 4-33 to 4-67 for the assignment of vulnerability class (VC) and damage grade for reinforced concrete (RC), steel and timber

Type of Structure		Abbrev.	Year Earthquake	VC	Damage Grade					Fig.
					1	2	3	4	5	
REINFORCED CONCRETE (RC) (Cast-in situ)	Frame	RC1	1988 Armenia	A					○	4-33
			1992 Turkey	A					○	4-34
			1995 Greece	A					○	4-35
			2023 Morocco	A					○	4-36
			2003 Turkey	B					○	4-37
	Frame with moderate level of Earthquake Resistant Design (ERD)	RC1-M	1976 Italy	B			○			4-38
			1985 Mexico	C			○			4-39
			1997 Venezuela	D			○			4-40
			1985 Mexico	C				○		4-41
			1987 Italy	C				○		4-42
			1995 Japan	C				○		4-43
			1995 Greece	B					○	4-44
			1995 Kobe	C					○	4-45
	Wall with moderate level of ERD	RC2-M	2010 Chile	D					○	4-46
	Wall with high level of ERD	RC2-H	1995 Kobe	E			○			4-47
			2010 Chile	E			○			4-48
	Dual System with moderate level of ERD	RC3-M	2010 Chile	D					○	4-49
	Flat Slab	RC4	2016 Ecuador	B			○			4-50
			2016 Ecuador	A				○		4-51
			2003 Algeria	A					○	4-52
RC (Precast)	Frame	RC5	2012 Switzerland	B	○					4-53
			2012 Italy	B				○		4-54
	Wall	RC6	2012 Italy	C				○		4-55
			2012 Italy	C				○		4-56
STEEL	Frame	S	1995 Kobe	D				○		4-57
			1995 Kobe	D					○	4-58
	Frame with moderate or high level of ERD	S-M/H	2011 New Zealand	E			○			4-59
TIMBER	Traditional	T1	1997 Venezuela	C		○				4-60
	Wall or Frame	T2	2017 Switzerland	D	○					4-61
			1999 Turkey	D			○			4-62
			1995 Kobe	C				○		4-63
			1999 Turkey	C				○		4-64
			1995 Kobe	C					○	4-65
	Wall with moderate or high level of ERD	T2-M/H	1994 USA	D				○		4-66
			1994 USA	E				○		4-67

2015 Gorkha, Nepal											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Rubble-Stone Masonry**	1	2	3	4	5
○	●								●		

Vulnerability Class B (VC B):
View of front facade of two-storey rubble-stone masonry building with regular layout in plan and in elevation. One VC higher than the most likely VC A for rubble-stone masonry, i.e., VC B is selected, still remaining in the range of the less probable, exceptional cases.

Damage Grade 3 (DG 3):
Large cracks in piers and spandrels of front facade as well as partial out-of-plane collapse of a portion of the facade wall below the roof imply damage grade 3 (moderate structural damage).

Photo: R. Adhikari, London

Fig. 4-1

2023 Jajarkot, Nepal												
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Rubble-Stone Masonry**	1	2	3	4	5

Vulnerability Class A:
View of two-storey rubble-stone masonry building. The river boulders are clearly visible in the forefront. Lack of bond between stones of facade wall and horizontally weak timber floor. The most likely VC for rubble-stone masonry, i.e., VC A should be selected.

Damage Grade 4:
Partial collapse of front facade wall. Partial failure of roof and floors. This is damage grade 4.

Photo: A. Dhakal, Kathmandu

Fig. 4-2

2023 Jajarkot, Nepal											
Vulnerability Class						Type of Structure **Rubble-Stone Masonry**	Damage Grade				
A	**B**	**C**	**D**	**E**	**F**		**1**	**2**	**3**	**4**	**5**
○	●									●	

Vulnerability Class B:
View of three-storey rubble-stone masonry building. The rubble stones are clearly visible in the forefront. There is a low mortar content in the wall debris on the ground. The layout in plan and elevation is regular. The interior walls are closely and regularly spaced. Due to these features, one VC higher than the most likely VC A, i.e., VC B. should be selected, still remaining in the range of the less probable, exceptional cases.

Damage Grade 4:
Nearly the complete front facade wall collapsed. This is damage grade 4.

Photo: G.B. Motra, Lalitpur

Fig. 4-3

1998 Ceyhan, Turkey											
Vulnerability Class						Type of Structure	Damage Grade				
A	**B**	**C**	**D**	**E**	**F**	**Rubble-Stone Masonry**	**1**	**2**	**3**	**4**	**5**
●	··|										●

Vulnerability Class A:
View of single-storey rubble-stone masonry building. The rubble stones are clearly visible in the forefront. The most likely VC for rubble-stone masonry is selected, i.e., VC A.

Damage Grade 5:
Several walls and part of the roof collapsed. This very heavy structural damage near total collapse is damage grade 5.

Photo: T. Wenk, Zurich

Fig. 4-4

<table>
<tr><th colspan="12">1995 Aegion, Greece</th></tr>
<tr><td colspan="6">Vulnerability Class</td><td rowspan="3">Type of Structure
Field-Stone Masonry</td><td colspan="5">Damage Grade</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>○</td><td>●</td><td></td><td></td><td></td><td></td><td></td><td></td><td>●</td><td></td><td></td></tr>
</table>

Vulnerability Class B:
View of two-storey field-stone masonry building. The field stones are clearly visible after the detachment of the outer wall shell. The vulnerability is affected by the connections between roof and upper wall edge as well as by several horizontal L-shaped timber elements distributed over the wall height. Because of these measures, one VC higher than the most likely VC A, i.e., VC B should be selected, still remaining in the range of the less probable, exceptional cases.

Damage Grade 3:
Large and extensive cracks in most walls. Some detachments of wall layers. But the damage is restricted to the upper storey and is not considered as a partial wall collapse. The damage is indicative of damage grade 3.

Photos: J. Schwarz, Weimar, T. Wenk, Zurich

Fig. 4-5

2023 Jajarkot, Nepal											
Vulnerability Class						Type of Structure	Damage Grade				
A	**B**	**C**	**D**	**E**	**F**	**Field-Stone Masonry**	**1**	**2**	**3**	**4**	**5**

Vulnerability Class A:
View of two-storey field-stone masonry building. The field stones are clearly visible in the forefront. The timber beams of the floor slab are running parallel to the front facade wall leading to an ineffective horizontal connection between floor and wall. The most likely VC for field-stone masonry is selected, i.e., VC A.

Damage Grade 4:
Out-of-plane collapse of nearly the complete front facade wall. This is indicative of damage grade 4.

Photo: G.B. Motra, Lalitpur

Fig. 4-6

1995 Aegion, Greece											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Field-Stone Masonry**	1	2	3	4	5
○	●									●	

Vulnerability Class B:
View of two-storey field-stone masonry building located at a street corner. The field stones are clearly visible in the left facade wall. The vulnerability is negatively affected by the corner cut-off, the timber floor, the timber roof, the poor quality of mortar and the non-effectiveness of the concrete elements in the construction. Positive aspects are the relatively thick, continuous wall piers.
Considered in an integral manner, one VC higher than the most likely VC A, i.e., VC B should be selected, still remaining in the range of the less probable, exceptional cases.

Damage Grade 4:
The serious failure of walls in this example is indicative of damage grade 4.

Photos: J. Schwarz, Weimar, T. Wenk, Zurich

Fig. 4-7

1980 Campania-Basilicata, Italy

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	Field-Stone Masonry	1	2	3	4	5
● ··· |											●

Vulnerability Class A:
View of three-storey field-stone masonry building. The field stones are clearly visible along the fracture surfaces of the walls. The vulnerability is affected by the timber floors as well as the timber roof. Because of these serious deficiencies (weak floor to wall connections, weak diaphragm action of floors), the most likely VC for field stone masonry is selected, i.e., VC A.

Damage Grade 5:
The floor slabs have failed and so have most of the walls. This very heavy structural damage near total collapse is damage grade 5.

Photo: H. Tiedemann, Zurich

Fig. 4-8

1990 Zaisan, Kazakhstan											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	Adobe Masonry	1	2	3	4	5
○—	●							●			

Vulnerability Class B:
Adobe-masonry building. Adobe units visible behind fallen plaster. One-storey building with compact rectangular layout in plan, lateral bracing pier and considerable wall thickness allows, remaining in the probable range, to assume one VC higher than the most likely VC A, i.e., VC B.

Damage Grade 2
Cracks in many walls suggest damage grade 2 (slight structural damage).

Photo: E.T. Kenjebaev, A.S. Taubaev, Almaty

Fig. 4-9

1986 Leova, Moldova											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Adobe Masonry**	1	2	3	4	5
○—	●								●		

Vulnerability Class B:
Adobe-masonry building. Adobe units visible behind fallen plaster. One-storey building with rectangular compact layout in plan, relatively long wall piers next to windows and considerable wall thickness allows, remaining in the probable range, to assume one VC higher than the most likely VC A, i.e., VC B.

Damage Grade 3:
The loss of connection between external walls and the partial failure at the bottom of the left corner suggest DG 3 (moderate structural damage). The right part of the building seems to be without serious damage.

Photo: E.T. Kenjebaev, A.S. Taubaev, Almaty

Fig. 4-10

2007 Pisco, Peru											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Adobe Masonry**	1	2	3	4	5
○	●								●		

Vulnerability Class B:
Adobe-masonry building. Adobe units visible in the facade walls behind fallen plaster. Two-storey building with rectangular compact layout in plan and regular layout in elevation with many continuous wall piers between wall openings. Therefore, one VC higher than the most likely VC A, i.e., VC B, but still remaining in the probable range, may be assumed.

Damage Grade 3:
Large cracks in most walls as well as outward shift of facade wall on the left imply damage grade 3 (moderate structural damage).

Photo: F. Taucer, Ispra

Fig. 4-11

2010 Maule, Chile											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Adobe Masonry**	1	2	3	4	5
○—	●								●		

Vulnerability Class B:
One-storey adobe-masonry building. Adobe units clearly visible in the detailed view on the left. Rectangular compact layout in plan and considerable wall thickness. These features allow, remaining in the probable range, to assume one VC higher than the most likely VC A, i.e., VC B.

Damage Grade 3:
Large and extensive cracks and fall of large pieces of plaster in most walls. Roof heavily damaged. This is damage grade 3.

Photos: T. Wenk, Zurich

Fig. 4-12

2008 Patras, Greece

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Adobe Masonry**	1	2	3	4	5
●	—									●	

Vulnerability Class A:
One-storey adobe-masonry agricultural building. The adobe units are clearly visible in the collapsed facade wall in the forefront. Lack of adequate diaphragm action of the roof does not justify the selection of a VC higher than the most likely VC A, even though the layout is regular in plan and in elevation.

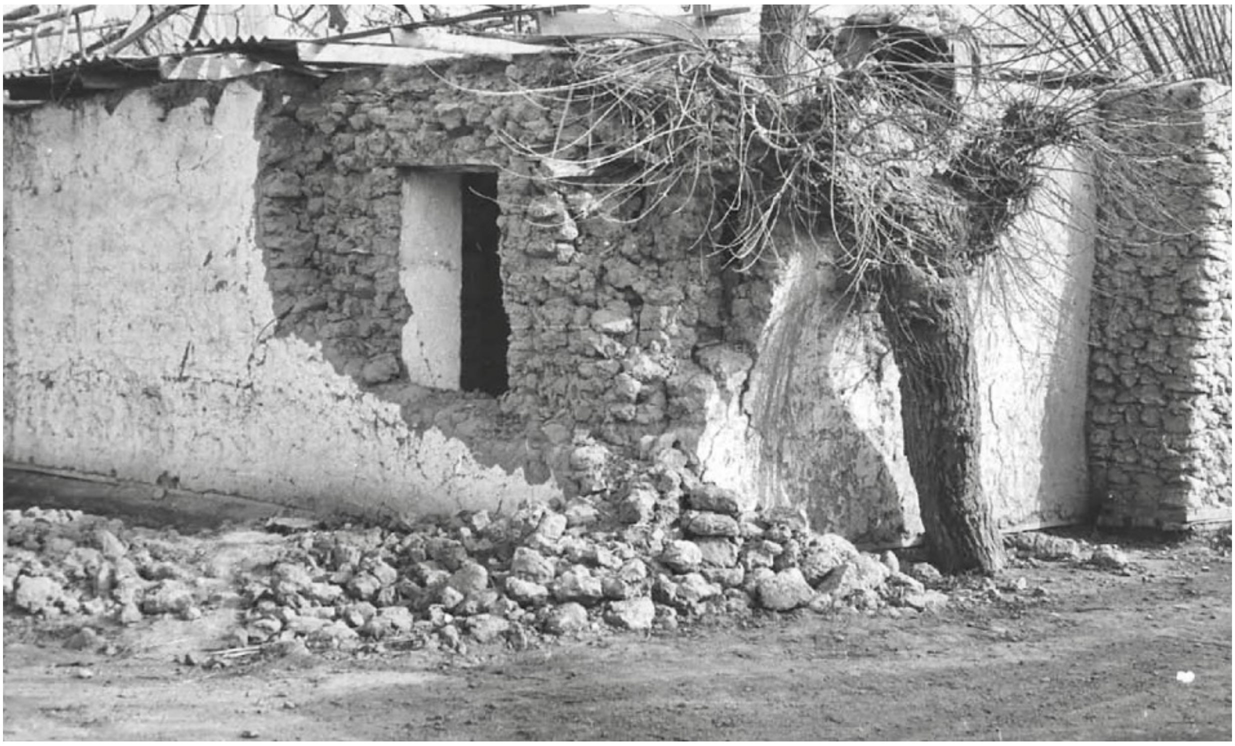
Damage Grade 4:
Serious failure of walls implies damage grade 4 (heavy structural damage).

Photo: T. Wenk, Zurich

Fig. 4-13

1985 Kayrakkum, Tajikistan

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Adobe Masonry**	1	2	3	4	5
○	●									●	



Vulnerability Class B:
Adobe-masonry building. Adobe units are clearly visible. One-storey building with regular compact layout in plan, lateral bracing pier and considerable wall thickness allows, remaining in the probable range, to assume one VC higher than the most likely VC A, i.e., VC B.

Damage Grade 4:
Serious failure of walls implies damage grade 4 (heavy structural damage).

Photo: E.T. Kenjebaev, A.S. Taubaev, Almaty

Fig. 4-14

1991 Vaz, Switzerland

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Simple-Stone Masonry**	1	2	3	4	5

Vulnerability Class B:
View of front facade of three-storey simple-stone masonry building. The vulnerability is also affected by timber floors. The most likely VC for simple-stone masonry is selected, i.e., VC B.

Damage Grade 2:
The long and clearly visible diagonal crack shown on the left is large enough to constitute slight structural damage. The damage grade should be considered as 2.

Photos: T. Wenk, Zurich

Fig. 4-15

1979 Montenegro											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Simple-Stone Masonry**	1	2	3	4	5
⊢···	●									●	

Vulnerability Class B:
View of front facade of three-storey simple-stone masonry building with timber floors. The most likely VC for simple-stone masonry is selected, i.e., VC B.

Damage Grade 4:
The masonry walls of the two upper stories of the front facade collapsed by an out-of-plane mechanism. This is due to a lack of horizontal restraint of the wall by the timber floor beams as they are running parallel to the front facade. In addition, the horizontal accelerations are greater in the upper stories compared with the first floor where the walls remain in place. As a partial structural failure, the damage grade should be considered as 4.

Photo: H. Tiedemann, Zurich

Fig. 4-16

2016 Amatrice, Italy											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Simple-Stone Masonry**	1	2	3	4	5
|···	●									●	

Vulnerability Class B:
Three-storey simple-stone masonry building with rectangular layout in plan and in elevation. Roof beams running parallel to the facade wall. The most likely VC for simple-stone masonry is selected, i.e., VC B.

Damage Grade 4:
Partial out-of-plane collapse of the top storey of the facade wall and partial roof collapse imply damage grade 4 (heavy structural damage).

Photo: D. D'Ayala, London, published by permission of EEFIT

Fig. 4-17

2012 Mirandola, Italy

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Massive-Stone Masonry**	1	2	3	4	5
	├	●	···┤				●				

Vulnerability Class C:
Two-storey office building in massive-stone masonry. The massive stones form the edges of the facade walls. The most likely VC for masonry with massive-stone units and timber floors is selected, i.e., VC C.

Damage Grade 1:
Fall of small pieces of plaster in the spandrels above the window vaults of the ground floor. The detailed view on the right is showing one of the spandrels with negligible to slight damage. This is damage grade 1.

Photos: T. Wenk, Zurich

Fig. 4-18

1999 Fribourg, Switzerland

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Massive-Stone Masonry**	1	2	3	4	5
	├	●	┤					●			

Vulnerability Class C:
Four-storey school building in massive-stone masonry. The massive stones form the edges of the facade walls. The most likely VC for masonry with massive stones and timber floors is selected, i.e., VC C.

Damage Grade 2:
There is no structural damage visible from the outside of the building. Some cracks opened inside, mainly in the roof vault shown in the detailed view on the right. This is damage grade 2.

Photos: T. Wenk, Zurich

Fig. 4-19

2016 Amatrice, Italy

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Massive-Stone Masonry**	1	2	3	4	5
	├	●	┤						●		

Vulnerability Class C:
Two-storey building in massive-stone masonry. The massive stones form the edges of the facade walls. The most likely VC for masonry with massive stones and timber floors is selected, i.e., VC C.

Damage Grade 3:
Damage concentrated in the short wall piers between windows in the ground floor. This is damage grade 3.

Photos: T. Wenk, Zurich

Fig. 4-20

2009 L'Aquila, Italy

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Massive-Stone Masonry**	1	2	3	4	5

Vulnerability Class C:
Two-storey building in massive-stone masonry. The massive stones form the edges of the facade walls as well as the door and window frames. The most likely VC for masonry with massive stones and timber floors is selected, i.e., VC C.

Damage Grade 4:
Serious out-of-plane failure of wall in second storey. Large vertical separation crack in the left corner of the front facade leaving the end wall with greatly reduced horizontal stabilisation. This is damage grade 4.

Photos: T. Wenk, Zurich

Fig. 4-21

1978 Swabian Alb, Germany

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Masonry with manu-factured units and timber floors**	1	2	3	4	5
|···	●	···|						●			

Vulnerability Class B:
Considering the basement, this is a two-storey masonry building. The long vertical separation crack between the gable wall and the longitudinal wall points at an insufficient horizontal connection between the two walls which is typical for timber floors. The most likely VC for masonry with manufactured units and with timber floors is selected, i.e., VC B.

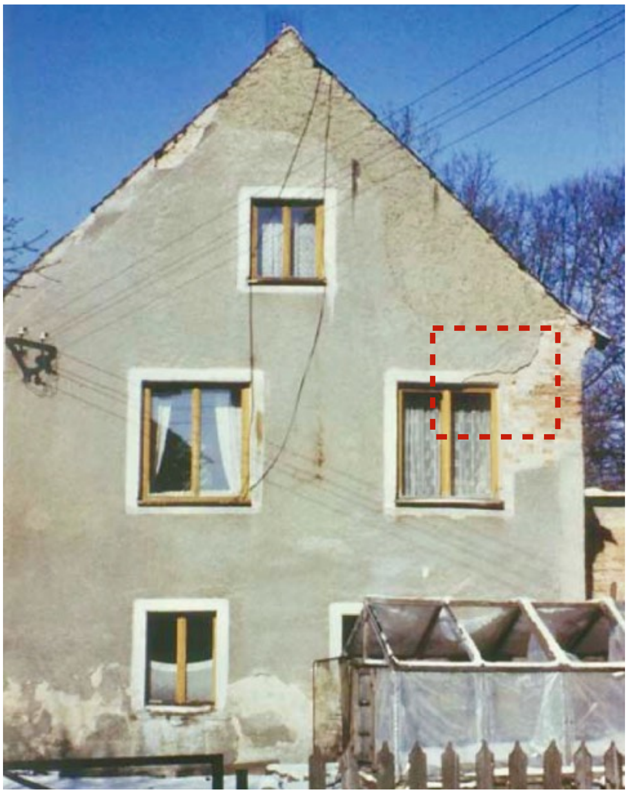
Damage Grade 2:
Many vertical cracks have appeared as a result of drift between walls. This is slight structural damage and the damage grade is 2.

Photo: P. Doll, Albstadt-Tailfingen

Fig. 4-22

1985 West Bohemia/Vogtland, Czech Republic

Vulnerability Class						Type of Structure	Damage Grade				
A	**B**	**C**	**D**	**E**	**F**	**Masonry with manu-factured units and timber floors**	**1**	**2**	**3**	**4**	**5**
|···	◉	···|						●			



Vulnerability Class B:
View of the gable facade of three-storey masonry building. The plaster on the right side already fell off before the earthquake making red bricks visible. The most likely VC for masonry with manufactured units and with timber floors is selected, i.e., VC B.

Damage Grade 2:
Although no structural damage is visible from outside the building, inside it can be observed that cracks have occurred along wall-ceiling edge, which is slight structural damage. Fairly large pieces of plaster have fallen from the exterior and plaster has also fallen from interior walls. This is damage grade 2.

Photos: G. Grünthal, Potsdam

Fig. 4-23

1992 Roermond, The Netherlands											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Masonry with manu-factured units and timber floors**	1	2	3	4	5
	●							●			

Vulnerability Class B:
Only the upper part of the front facade with red bricks is visible. The most likely VC for masonry with manufactured units and with timber floors is selected, i.e., VC B.

Damage Grade 2:
Several chimneys have been damaged and tiles on the roof have been shifted. Large and extensive cracks in most walls were not observed, and therefore the damage is to be assessed as grade 2.

Note: The broken chimney on the left of the picture fell down perhaps due to pounding of the two adjoining buildings. Parts of the broken chimney hit the roof and dislodged tiles; this damage to the tiles is therefore a secondary effect and not caused directly by the earthquake shaking.

Photo: G. Grünthal, Potsdam

Fig. 4-24

<table>
<tr><th colspan="13">1996 Emilia-Romagna, Italy</th></tr>
<tr><td colspan="6">Vulnerability Class</td><td rowspan="3">Type of Structure

Masonry with manu-factured units and timber floors</td><td colspan="5">Damage Grade</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>|··</td><td>●</td><td>··|</td><td></td><td></td><td></td><td></td><td>●</td><td></td><td></td><td></td></tr>
</table>

Vulnerability Class B:
Two-storey masonry building. The manufactured units are visible where the plaster spalled off. The most likely VC for masonry with manufactured units and with timber floors is selected, i.e., VC B.

Damage Grade 2:
Many X-shaped cracks in six masonry spandrels below and above window openings of the longitudinal facade. The crack widths are relatively thin indicating damage grade 2.

Photo: A. Tertulliani, Rome

Fig. 4-25

1976 Friuli, Italy											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	Masonry with manu-factured units and timber floors	1	2	3	4	5
|···	●	···|							●		

Vulnerability Class B:
Two-storey masonry building. The manufactured units are visible where the plaster spalled off. The most likely VC for masonry with manufactured units and with timber floors is selected, i.e., VC B.

Damage Grade 3:
There are large diagonal cracks in most walls, but none of the walls has completely failed. In this case the damage grade is still 3.

Photo: D. Molin, Rome

Fig. 4-26

1976 Friuli, Italy											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Masonry with manufactured units and timber floors**	1	2	3	4	5
|···	●	···|							●		

Vulnerability Class B:
Two-storey masonry building. The manufactured units are visible where the plaster spalled off. The most likely VC for masonry with manufactured units and with timber floors is selected, i.e., VC B.

Damage Grade 3:
There are large diagonal cracks in the walls of the ground floor, but none of the walls has completely failed. In this case the damage grade is still 3.

Photo: D. Molin, Rome

Fig. 4-27

2009 L'Aquila, Italy

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Masonry with manufactured units and timber floors**	1	2	3	4	5
|···	●	···|							●		

Vulnerability Class B:
Two-storey masonry building. The manufactured units are visible where the plaster spalled off. The most likely VC for masonry with manufactured units and with timber floors is selected, i.e., VC B.

Damage Grade 3:
Out-of-plane failure of upper storey of front facade wall. This damage grade is still 3 as the wall did not fall to the ground.

Photos: T. Wenk, Zurich

Fig. 4-28

1979 Montenegro

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	Masonry with manu-factured units and timber floors	1	2	3	4	5
|···	●	···|								●	

Vulnerability Class B:
View of front facade of four-storey masonry building with timber floors. Small anchor plates can be seen regularly spaced at the third floor level. The most likely VC for masonry with manufactured units and timber floors is selected, i.e., VC B.
Previously, the building has been classified as simple-stone masonry building in EMS-92 (Figure A-8) as well as in EMS-98 (Figure 5-7). A closer look at the remaining longitudinal gable wall reveals a regular and orthogonal pattern of bed and head joints typical for masonry with manufactured units.

Damage Grade 4:
The short longitudinal gable wall of the central roof structure collapsed by an out-of-plane mechanism. As a serious wall failure, the damage grade should be considered as 4.

Photo: H. Tiedemann, Zurich

Fig. 4-29

2016 Norcia, Italy											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Masonry with manu-factured units and timber floors**	1	2	3	4	5

Vulnerability Class C:
Two-storey masonry building with manufactured units and timber floors embedded between neighbouring two-storey buildings. Several 19th century Earthquake-Resistant Design (ERD) features can be detected:

- The front facade wall thickness increases from mid-height of the second storey down to ground level.
- Triangular shaped supporting massive-stone pier in the middle of the front facade.
- Framing of door and window openings by large size natural stones.
- Wall anchor at roof level.
- Number of stories limited to two.

These ERD features allow to assume one VC higher than the most likely VC B, i.e., VC C. VC C is still in the range of less probable, exceptional cases.

Damage Grade 1:
Fall of small pieces of plaster visible in the detailed view. Note that the plaster is reinforced by a wire mesh. This is damage grade 1.

Photos: T. Wenk, Zurich

Fig. 4-30

1995 Aegion, Greece

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Masonry with manufactured units and RC floors**	1	2	3	4	5

Vulnerability Class C:
Two-storey masonry building with manufactured units and Reinforced Concrete (RC) floors. The visible RC balcony with its RC corbels are an indication of RC floors. The most likely VC for masonry with manufactured units and with RC floors is selected, i.e., VC C.

Damage Grade 3:
Most walls in the first and second floor have large and extensive X-shaped cracks as shown in the detailed view on right. This is moderate structural damage and, therefore, damage grade 3.

Photos: T. Wenk, Zurich

Fig. 4-31

2015 Ghorka, Nepal

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Confined Masonry**	1	2	3	4	5

Vulnerability Class C:
View of gable wall of a one-storey natural-stone masonry building with reinforced concrete framing connecting the two window frames to the corner columns. Example is not confined masonry according to Structural Standards as most of its rules are not followed, e.g., the confining elements should have been cast before instead of after the masonry has been built (visible through the smooth edges of the confining elements). Also, instead of a mortar of higher quality, no mortar at all was used. Nevertheless, the confining elements together with the layers of elongated stones provide some improvement of seismic behaviour. These features allow to assume confined masonry but with one VC lower than the most likely VC D, i.e., VC C. VC C is still in the range of less probable, exceptional cases.

Damage Grade 1:
Fall of loose stones from upper part of gable wall where RC confining elements are missing. This is typical of damage grade 1.

Photo: M. Basnet, Weimar

Fig. 4-32

1988 Spitak, Armenia											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	Reinforced Concrete Frame	1	2	3	4	5

Vulnerability Class A:
The debris of this multi-storey Reinforced Concrete (RC) frame building present many deficiencies. In particular, a lack of diaphragm action of the floor slabs is illustrated by how the precast elements without rebars have fallen down. Also, there is a lack of rebars connecting the two RC beams to the columns visible in the center of the photo. This building is a typical example where one should assign a low vulnerability class, in this case the lowest VC in the range of less probable, exceptional cases for RC frames without Earthquake-Resistant Design is selected, i.e., VC A.

Damage Grade 5:
This is very heavy structural damage and total collapse. Therefore, the damage grade is 5.

Photo: H. Tiedemann, Zurich

Fig. 4-33

1992 Erzincan, Turkey

Vulnerability Class						Type of Structure	Damage Grade				
A	**B**	**C**	**D**	**E**	**F**	**Reinforced Concrete Frame**	**1**	**2**	**3**	**4**	**5**
● (most likely)		○ (range)									●

Vulnerability Class A:
Four-storey Reinforced Concrete (RC) frame building with many deficiencies of Earthquake-Resistant Design (ERD). In particular, masonry infills, also some partial infills, in the RC frame and a few column bottoms are hinged into the slab. This building is a typical example where one should assign a low vulnerability class, in this case the lowest VC in the range of less probable, exceptional cases for RC frames without ERD is selected, i.e., VC A.

Damage Grade 5:
This is very heavy structural damage and total collapse of several stories. Therefore, the damage grade is 5.

Photo: H. Grosser, Potsdam

Fig. 4-34

1995 Aegion, Greece											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	Reinforced Concrete Frame	1	2	3	4	5

Vulnerability Class A:
View of Reinforced Concrete (RC) frame building with infills and a horizontally soft ground floor. The detail view on the left shows the left building corner with the punching shear failure through the slab of the thin column. Note the absence of connecting rebars running from the column into the slab as well as of stirrups in the column.
Because of these serious deficiencies, the lowest VC still in the range of less probable, exceptional cases for RC frames without Earthquake-Resistant Design is selected, i.e., VC A.

Damage Grade 5:
This whole ground floor has collapsed completely. In such cases the damage grade is 5.

Photos: J. Schwarz, Weimar, T. Wenk, Zurich

Fig. 4-35

2023 Al Haouz, Morocco

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Reinforced Concrete Frame**	1	2	3	4	5
●		○									●

Vulnerability Class A:
View of two similar two-storey Reinforced Concrete (RC) frame buildings with partial masonry infills. The building on the right suffered a soft-storey collapse in the ground floor. This building is a typical example where one should assign a low vulnerability class, in this case the lowest VC of the range of less probable, exceptional cases for RC frames without Earthquake-Resistant Design is selected, i.e., VC A.

Damage Grade 5:
The soft-storey collapse of the building on the right is very heavy structural damage and total collapse. Therefore, the damage grade is 5.

Photo: S. Saloustros, Lausanne, https://doi.org/10.5281/zenodo.11191321

Fig. 4-36

2003 Bingöl, Turkey											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Reinforced Concrete Frame**	1	2	3	4	5
|···	●	—O	···|								●

Vulnerability Class B:
View of three-storey school building. The type of structure is a Reinforced Concrete (RC) frame with masonry infills. The reason for the collapse of the ground floor may be large openings in the masonry infill on the very left of the ground floor of the longitudinal facade. Considering also the deficiencies of the reinforcement of the failed edge columns, i.e., thin and widely spaced stirrups with opened hooks shown in the detailed view, as well as the problematic infills, the VC one class lower than the most likely VC C for RC frames, but still in the probable range, is selected, i.e., VC B.

Damage Grade 5:
The ground floor collapsed completely, the second floor partially. This is damage grade 5.

Photo: H. Maiwald, Weimar

Fig. 4-37

1976 Friuli, Italy

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	Reinforced Concrete Frame with moderate level of ERD	1	2	3	4	5
	●		○						●		

Vulnerability Class B:
View of three-storey Reinforced Concrete (RC) frame building in construction phase with relatively thin columns in the ground floor as well as some regular infills without openings in the upper floors. Due to serious deficiencies such as a soft-storey in the ground floor and a very heavy roof structure, the lowest VC in the range of the less probable, exceptional cases for RC frames with moderate level of Earthquake-Resistant Design (ERD) is selected, i.e., VC B.

Damage Grade 3:
The important drift of the ground storey together with the out-of-plane failure of only one span of infills in the ground storey of the gable wall justifies the selection of damage grade 3.

Photo: H. Tiedemann, Zurich

Fig. 4-38

1985 Michoacán, Mexico

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Reinforced Concrete Frame with moderate level of ERD**	1	2	3	4	5

Vulnerability Class C:
High-rise Reinforced Concrete (RC) frame building with masonry infills with regular layout in plan and elevation. The infills are subdivided by thinner RC elements at mid-height between RC floor slabs and at mid-width between RC columns. But, despite of this Earthquake-Resistant Design (ERD) feature, very few of the infills collapsed out-of-plane leaving the bare RC frame more vulnerable. Due to this deficiency, VC C is selected, still remaining in the probable range for RC frames with moderate level of ERD, but one class lower than the most likely VC D.

Damage Grade 3:
This building has suffered cracks in RC columns and slabs as well as infills, detachment of pieces of plaster and failure of very few infill walls. The structural damage to the RC elements is moderate, and only very few infill walls of the high-rise building collapsed, the damage grade is 3.

Photo: H. Tiedemann, Zurich

Fig. 4-39

1997 Cariaco, Venezuela

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Reinforced Concrete Frame with moderate level of ERD**	1	2	3	4	5

Vulnerability Class D:
Three-storey Reinforced Concrete (RC) frame building with regular layout in plan and elevation. The concrete columns in the ground floor reveal several Earthquake-Resistant Design (ERD) features of the reinforcement thanks to spalling of the concrete cover: thick diameter of vertical bars, close spacing of stirrups and even closer spacing in the critical end zones of the columns with additional hooks for the two vertical bars between the corner bars (see detailed view on the right). Due to these features, VC D, the most likely VC for RC frames with moderate level of ERD, is selected.

Damage Grade 3:
The extensive concrete spalling of the columns in the ground floor exceed the damage typical for DG 2 (slight structural damage). Therefore, the damage grade is classified as 3.

Photo: D.H. Lang, Weimar

Fig. 4-40

1985 Michoacán, Mexico											
Vulnerability Class						Type of Structure	Damage Grade				
A	**B**	**C**	**D**	**E**	**F**	**Reinforced Concrete Frame with moderate level of ERD**	**1**	**2**	**3**	**4**	**5**
	├··	●	○	··┤						●	

Vulnerability Class C:
Multi-storey Reinforced Concrete (RC) frame building with irregular layout in elevation. Due to this deficiency, the VC one class lower than the most likely VC for RC frames with moderate level of Earthquake-Resistant Design (ERD), but still in the probable range, is selected, i.e., VC C.

Damage Grade 4:
The two top floors collapsed, while the lower floors remained in place. In such cases of partial collapse, the damage grade is 4.

Photo: H. Tiedemann, Zurich

Fig. 4-41

<table>
<tr><th colspan="6">1987 Irpinia-Basilicata, Italy</th><th></th><th colspan="5"></th></tr>
<tr><td colspan="6">Vulnerability Class</td><td rowspan="3">Type of Structure

Reinforced Concrete Frame with moderate level of ERD</td><td colspan="5">Damage Grade</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td></td><td>├</td><td>●</td><td>○</td><td>┤</td><td></td><td></td><td></td><td></td><td>●</td><td></td></tr>
</table>

Vulnerability Class C:
Multi-storey Reinforced Concrete (RC) frame building with masonry infills with irregular layout in plan. The relatively thick corner columns point at moderate level of Earthquake-Resistant Design (ERD). Most of the infills collapsed out-of-plane, in particular those with window or door openings. Due to this deficiency, the VC one class lower than the most likely VC for frames with moderate level of ERD, but still in the probable range, is selected, i.e., VC C.

Damage Grade 4:
Many infill walls failed entirely out-of-plane, which is very heavy non-structural damage. In a few cases there is damage to the beam-column joints. This is damage grade 4.

Photo: H. Tiedemann, Zurich

Fig. 4-42

1995 Kobe, Japan											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	Reinforced Concrete Frame with moderate level of ERD	1	2	3	4	5
		●	○							●	

Vulnerability Class C:
Multi-storey Reinforced Concrete (RC) frame building with irregular layout in plan. The anchorage of the heavy facade elements to the RC beams as well as to an additional steel frame was insufficient. Due to this deficiency, the VC one class lower than the most likely VC D for RC frames with moderate Earthquake-Resistant Design (ERD), still in the probable range, is selected, i.e., VC C.

Damage Grade 4:
Many heavy facade elements have collapsed. In addition, there is heavy damage to the RC frame and to the steel frame. This should be assessed as damage grade 4.

Photo: T. Wenk, Zurich

Fig. 4-43

1995 Aegion, Greece

Vulnerability Class						Type of Structure	Damage Grade				
A	**B**	**C**	**D**	**E**	**F**	**Reinforced Concrete Frame with moderate level of ERD**	**1**	**2**	**3**	**4**	**5**

Vulnerability Class B:
Multi-storey Reinforced Concrete (RC) frame building with masonry infills and with irregular layout in plan and in elevation (soft-storey in ground floor). Because of these deficiencies, one should assign a low vulnerability class, in this case VC B, which represents an exceptionally low class for RC frames with moderate level of Earthquake-Resistant Design (ERD). VC B is still in the range of less probable, exceptional cases.

Damage Grade 5:
The middle part of the building has collapsed completely, reaching damage grade 5.

Photo: T. Wenk, Zurich

Fig. 4-44

1995 Kobe, Japan											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Reinforced Concrete Frame with moderate level of ERD**	1	2	3	4	5

Vulnerability Class C:
Six-storey Reinforced Concrete (RC) frame building with moderate level of Earthquake-Resistant Design (ERD). Some features of ERD are visible in the photo on the left such as thick vertical rebars with limited restraint by stirrups. Large openings in the ground floor walls caused a soft-storey collapse. Due to this deficiency, the VC one class lower than the most likely VC D for RC frames with moderate ERD, still in the probable range, is selected, i.e., VC C.

Damage Grade 5:
This whole ground floor has collapsed completely. In such cases the damage grade is 5.

Photos: T. Wenk, Zurich

Fig. 4-45

<table>
<tr><th colspan="13">2010 Maule, Chile</th></tr>
<tr><td colspan="6">Vulnerability Class</td><td rowspan="3">Type of Structure

Reinforced Concrete Walls with moderate level of ERD</td><td colspan="5">Damage Grade</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td></td><td></td><td></td><td>●</td><td>○</td><td></td><td></td><td></td><td></td><td></td><td>●</td></tr>
</table>

Vulnerability Class D:
View of eleven-storey building with several Reinforced Concrete (RC) walls (cast-in-situ) in both horizontal directions. The layout in plan and in elevation is regular. The detailed view shows the broken transverse facade wall in the ground floor. One VC lower than the most likely VC E, i.e., VC D, is selected.

Damage Grade 5:
The transverse walls failed in the ground floor and the building toppled over. The upper six stories probably broke away from the stories below after impact with the ground. This is damage grade 5.

Photos: T. Wenk, Zurich

Fig. 4-46

1995 Kobe, Japan

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Reinforced Concrete Walls with high level of ERD**	1	2	3	4	5
			⊢ · ·	●	—⊣				●		

Vulnerability Class E:
View of Reinforced Concrete (RC) building (cast-in-situ) with several RC walls running without interruption over all stories. Evenly distributed crack damage over all stories. Two walls are coupling elements at every storey height. Recognising these typical Earthquake-Resistant Design (ERD) features, the most likely VC for RC walls with high level of ERD is selected, i.e., VC E.

Damage Grade 3:
This building has suffered moderate structural damage over its full height. The cracks are concentrated in the short columns of the outer facade. The integrity of the whole building has not been impaired. The damage grade is assessed as 3.

Photo: T. Wenk, Zurich

Fig. 4-47

2010 Maule, Chile

<table>
<tr><th colspan="6">Vulnerability Class</th><th rowspan="3">Type of Structure

Reinforced Concrete Walls with high level of ERD</th><th colspan="5">Damage Grade</th></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td></td><td></td><td></td><td>├···</td><td>●</td><td>──┤</td><td></td><td></td><td>●</td><td></td><td></td></tr>
</table>

Vulnerability Class E:
View of multi-storey building with several cast-in-situ Reinforced Concrete (RC) walls in both horizontal directions and running over all stories.
The detailed view shows one of these long and thick RC walls in the basement. Spalled concrete reveals the typical Earthquake-Resistant Design (ERD) features of thicker vertical bars next to the wall edge as well as relatively close spaced horizontal rebars. On the other hand, the lack of adequate confinement reinforcement of the thicker vertical bars does not allow to go one VC higher than the most likely VC E for RC walls with high level of ERD.

Damage Grade 3:
Concrete spalling and lateral buckling of vertical bars occurred in several walls in the lower floors as shown in the detailed view for one wall in the basement. The damage grade is assessed as 3.

Photos: T. Wenk, Zurich

Fig. 4-48

2010 Maule, Chile

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	Reinforced Concrete Dual System with moderate ERD level	1	2	3	4	5
			●	○	┤					●	

Vulnerability Class D:
View of 20-storey building with a dual system of cast-in-situ Reinforced Concrete (RC) walls and frames. The layout in elevation is irregular with setbacks at mid-height and at 3/4 height. Several walls und columns are interrupted at the level of these setbacks. The detailed view shows the upper half of the building which fell down one storey due to the storey collapse at mid-height. Because of these irregularities, one VC lower than the most likely VC E, i.e., VC D, is selected.

Damage Grade 4:
Storey collapse at mid-height in a storey with setbacks. As a partial structural failure of the building, the damage grade should be considered as 4.

Photos: T. Wenk, Zurich

Fig. 4-49

2016 Muisne, Ecuador											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Reinforced Concrete Flat Slab**	1	2	3	4	5
	●								●		

Vulnerability Class B:
View of five-storey Reinforced Concrete (RC) flat-slab building with a ground floor without openings. The layout in elevation is irregular with a horizontally soft-storey in the first storey. In addition, there is a setback of the front facade in the first storey with respect to the upper three stories. Considering these deficiencies, the most likely VC for RC flat-slab buildings without Earthquake-Resistant Design (ERD), i.e., VC B, is selected.

Damage Grade 3:
Infill walls of the second floor and some infill wall parts of the first floor as well as the third floor collapsed. This is heavy non-structural damage only. The RC columns including the column-slab connections in the first floor show only moderate structural damage, i.e., the damage grade is 3.

Photo: J. Sosa, Weimar

Fig. 4-50

2016 Muisne, Ecuador

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Reinforced Concrete Flat Slab**	1	2	3	4	5
●	○									●	

Vulnerability Class A:
View of four-storey Reinforced Concrete (RC) flat-slab building. The layout in elevation is irregular with a horizontally relatively weak upper stories and a soft-storey in the first storey. This building is a typical example where one should assign a low vulnerability class, in this case VC A, which represents an exceptionally low class for RC frame structures with flat slabs and without Earthquake-Resistant Design (ERD).

Damage Grade 4:
The first floor partially collapsed. The second floor has heavy structural damage. The damage grade should be assessed as 4.

Photo: J. Sosa, Weimar

Fig. 4-51

2003 Boumerdès, Algeria

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Reinforced Concrete Flat Slab**	1	2	3	4	5

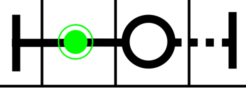
Vulnerability Class A:
View of the pancake like debris of a five-storey Reinforced Concrete (RC) flat-slab building with some partial masonry infills. The rather close spacing of the collapsed RC flat slabs suggests that there were mainly thin columns in between them. The detailed view shows failed thin RC columns with inadequate rebar connections to the flat slab.
This building is a typical example where one should assign a low vulnerability class, in this case A, which represents an exceptionally low class for RC structures without Earthquake-Resistant Design (ERD).

Damage Grade 5:
This is very heavy structural damage and total collapse. Therefore, the damage grade is 5.

Photos: T. Wenk, Zurich

Fig. 4-52

2012 Allenwinden, Switzerland

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Precast Reinforced Concrete Frame**	1	2	3	4	5
							●				

Vulnerability Class B:
One-storey gym structure with heavy precast Reinforced Concrete (RC) roof girders. The seat width of the girders on the facade wall is relatively small. Due to this deficiency, one VC lower than the most likely VC C, i.e., VC B, is selected.

Damage Grade 1:
The building has suffered no damage except two thin diagonal cracks at the edges of the seating of the precast girder. The damage grade should be assessed as 1.

Photos: T. Wenk, Zurich

Fig. 4-53

2012 Emilia-Romagna, Italy											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Precast Reinforced Concrete Frame**	1	2	3	4	5
										●	

Vulnerability Class B:
Two-storey warehouse with pizzeria in ground floor constructed as precast Reinforced Concrete (RC) frame. Facade walls built from heavy precast RC elements which are participating in laterally stiffening the warehouse. The VC one class lower than the most likely VC C for precast RC frames without Earthquake-Resistant Design (ERD), still in the probable range, is selected, i.e., VC B.

Damage Grade 4:
Out-of-plane collapse of the precast RC elements of the longitudinal facade wall. As a partial structural failure, the damage grade should be considered as 4.

Photo: T. Wenk, Zurich

Fig. 4-54

2012 Emilia-Romagna, Italy

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Precast Reinforced Concrete Wall**	1	2	3	4	5
	|—	●	···|							●	

Vulnerability Class C:
One-storey warehouse with facade walls constructed from precast Reinforced Concrete (RC) wall elements. The most likely VC for precast RC walls is selected, i.e., VC C.

Damage Grade 4:
Out-of-plane collapse of the large precast RC elements of the longitudinal facade wall. As a partial structural failure, the damage grade should be considered as 4.

Photo: T. Wenk, Zurich

Fig. 4-55

2012 Emilia-Romagna, Italy

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Precast Reinforced Concrete Wall**	1	2	3	4	5
	├	●	┤							●	

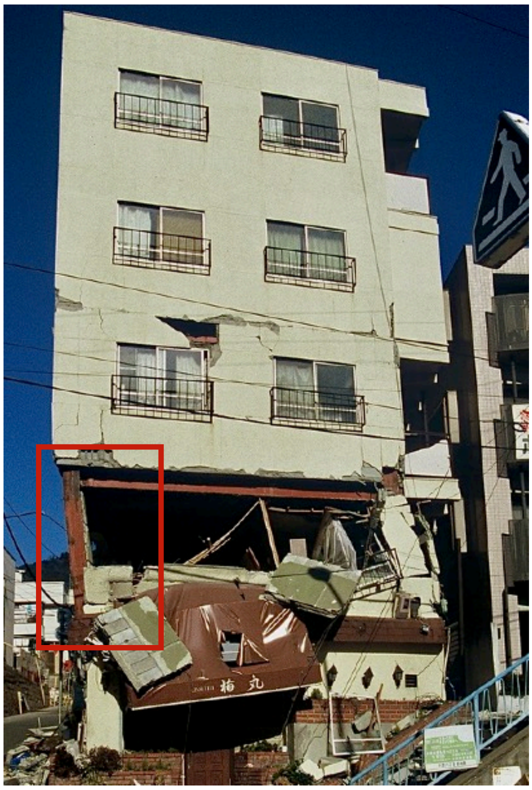
Vulnerability Class C:
Two-storey office building connected to one-storey warehouse with facade walls constructed from precast Reinforced Concrete (RC) walls or from masonry cladding. The most likely VC for precast RC walls is selected, i.e., VC C.

Damage Grade 4:
Out-of-plane collapse of the large precast RC elements of the longitudinal facade wall. As a partial structural failure, the damage grade should be considered as 4.

Photo: T. Wenk, Zurich

Fig. 4-56

1995 Kobe, Japan											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Steel Frame**	1	2	3	4	5
		|…	●	–…	…|					●	



Vulnerability Class D:
Building with a four-storey steel frame resting on a ground storey in Reinforced Concrete (RC). No features of Earthquake-Resistant Design (ERD) are visible. The most likely VC for steel frames without ERD, i.e., VC D, should be assumed.

Damage Grade 4:
Very heavy structural damage in the lowest floor of the steel frame. The photo on the right shows the foot plate of the corner column in a near collapse situation. This is damage grade 4.

Photos: T. Wenk, Zurich

Fig. 4-57

1995 Kobe, Japan											
Vulnerability Class						**Type of Structure**	**Damage Grade**				
A	**B**	**C**	**D**	**E**	**F**	**Steel Frame**	**1**	**2**	**3**	**4**	**5**
		├┈	●	─┈	┤						●

Vulnerability Class D:
Three-storey steel-frame building. The steel columns were connected by friction without bolts or welding. No features of Earthquake-Resistant Design (ERD) are visible. The most likely VC for steel frames, i.e., VC D, should be assumed.

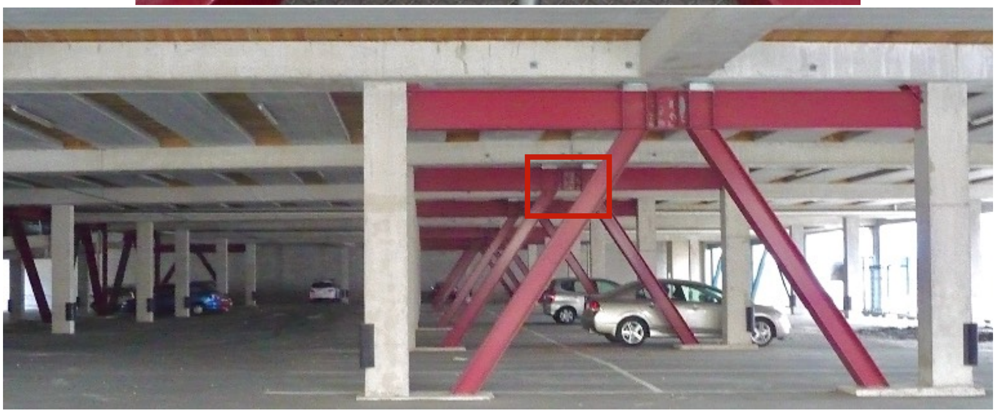
Damage Grade 5:
Complete destruction. The steel frame broke apart in the ground floor and the building toppled over. This is damage grade 5.

Photos: T. Wenk, Zurich

Fig. 4-58

2011 Christchurch, New Zealand

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Steel Frame with high level of ERD**	1	2	3	4	5



Vulnerability Class E:
View into the first floor of a parking building seismically retrofitted by eccentrically braced steel frames (lower photo). Detail view of an eccentrically braced connection of a steel frame (upper photo). Recognising this typical detail of high level of Earthquake-Resistant Design (ERD) of the added steel frames allows to assume the type of structure "steel frame with high level of ERD" and its most likely VC, i.e., VC E.

Damage Grade 3:
Detachment of red paint due to plastic deformation in many shear links between connections and weld fracture of the left diagonal suggests damage grade 3 (moderate damage).

Photos: M. Bruneau, Buffalo

Fig. 4-59

<table>
<tr><th colspan="12">1997 Cariaco, Venezuela</th></tr>
<tr><td colspan="6">Vulnerability Class</td><td rowspan="3">Type of Structure

Traditional Timber</td><td colspan="5">Damage Grade</td></tr>
<tr><td>**A**</td><td>**B**</td><td>**C**</td><td>**D**</td><td>**E**</td><td>**F**</td><td>**1**</td><td>**2**</td><td>**3**</td><td>**4**</td><td>**5**</td></tr>
<tr><td></td><td></td><td>●</td><td></td><td></td><td></td><td></td><td>●</td><td></td><td></td><td></td></tr>
</table>

Vulnerability Class C:
One-storey lightweight traditional timber structures in tropical regions covered with thatch or mud-plastered walls of bamboo or reeds (*Bahareque* in Central and South America). This type of structure has demonstrated a superior seismic performance compared to unreinforced masonry. The most likely VC, i.e., VC C should be assumed.

Damage Grade 2:
The damage is limited to spalling of the plaster cover outside the confinement by the traditional timber mesh. This is damage grade 2.

Photos: M. Raschke, Weimar

Fig. 4-60

2017 Linthal, Switzerland

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Timber Wall**	1	2	3	4	5

Vulnerability Class D:
Two-storey timber-log structure building resting on Reinforced Concrete (RC) basement in the typical Alpine chalet style. Remaining in the probable range for timber frames or walls without Earthquake-Resistant Design (ERD), the most likely VC D should be assumed.

Damage Grade 1:
The building has suffered no damage except a very small horizontal displacement of the complete log structure on the underlaying RC basement as well as hair line cracks in the corner of the support (detail picture on the left). The damage grade should be assessed as 1.

Photos: T. Wenk, Zurich

Fig. 4-61

1999 Düzce, Turkey											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Timber Frame**	1	2	3	4	5
	├···	──	●	─┤					●		

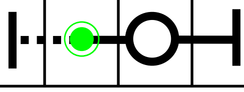
Vulnerability Class D:
Two-storey half-timbered frame structure consisting of timber logs and braced posts with masonry infills. Remaining in the probable range for timber frames or walls without Earthquake-Resistant Design (ERD), the most likely VC D should be assumed.

Damage Grade 3:
The building has suffered substantial to heavy damage as some units of the masonry infills fell out. In addition, some shifting of unsecured foundations occurred. The damage grade should be assessed as 3.

Photos: D.H. Lang, Weimar

Fig. 4-62

<table>
<tr><th colspan="12">1995 Kobe, Japan</th></tr>
<tr><td colspan="6">Vulnerability Class</td><td rowspan="3">Type of Structure

Timber Frame</td><td colspan="5">Damage Grade</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td></td><td colspan="4"></td><td></td><td></td><td></td><td></td><td>●</td><td></td></tr>
</table>

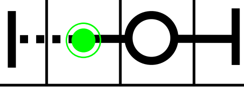
Vulnerability Class C:
In the ground floor, the timber frame of this two-storey building became visible behind the sheathing. The large opening in the ground floor created a soft storey. The lack of stiff connections points to a timber frame without Earthquake-Resistant Design (ERD). Remaining in the probable range for timber frames or walls without ERD, one VC lower than the most likely VC D, i.e., VC C should be assumed.

Damage Grade 4:
The building on the right has suffered heavy damage to the joints of the building frame. The damage grade should be assessed as 4.

Note: Due to the weakness of the horizontal stiffening system of the ground storey (soft storey), the whole building has drifted to the left. Lateral support was provided by the building next door, so that in this case the collapse of the building is not total. An illustration of the effect that can be played by the position of a building relative to neighbouring buildings.

Photo: T. Wenk, Zurich

Fig. 4-63

1999 Düzce, Turkey											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Timber Frame**	1	2	3	4	5
											

Vulnerability Class C:
Two-storey half-timbered frame structure consisting of a braced timber frame with masonry infills and plaster. The vulnerability is affected by large window openings in the ground floor corner and by the poor state of preservation. Because of these deficiencies, VC C is selected remaining in the probable range for timber frames or walls without Earthquake-Resistant Design (ERD), but one class lower than the most likely VC.

Damage Grade 4:
The building has suffered very heavy damage. Serious failure of walls around the ground-floor corner with the large openings. The damage grade should be assessed as 4.

Photos: D.H. Lang, Weimar

Fig. 4-64

1995 Kobe, Japan											
Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	Timber Frame	1	2	3	4	5
	|···	●	○	—|							●

Vulnerability Class C:
Two-storey timber-frame building without Earthquake-Resistant Design (ERD). Remaining in the probable range for timber frames or walls without ERD, one VC lower than the most likely VC D, i.e., VC C should be assumed.

Damage Grade 5:
Complete destruction. This is damage grade 5.

Photo: T. Wenk, Zurich

Fig. 4-65

2003 San Simeon, USA

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Timber Wall with moderate level of ERD**	1	2	3	4	5
			● (most likely E, range D–F)							●	

Vulnerability Class D:
View of two-storey timber-wall building resting on unstable sill beams. The facade walls have only small openings and remained relatively undamaged after the building fell off the sill beams. These are signs of moderate Earthquake-Resistant Design (ERD).
Considering the serious deficiency of the unstable sill beam, the VC one class lower than the most likely VC E for timber-wall structures with moderate ERD is selected, i.e., VC D. VC D is still in the range of less probable, exceptional cases.

Damage Grade 4:
The failure of the sill beams, see detailed view on the right, lead to a large horizontal and vertical displacement of the building. This is damage grade 4.

Photos: D. Dyce, Sacramento

Fig. 4-66

1994 Northridge, USA

Vulnerability Class						Type of Structure	Damage Grade				
A	B	C	D	E	F	**Timber Wall with moderate level of ERD**	1	2	3	4	5

Vulnerability Class E:
View of two-storey timber-wall building. The moderate openings in the facade walls allow to assume that some Earthquake-Resistant Design (ERD) has been respected. Therefore, the most likely VC E for timber-wall structures with moderate ERD is selected.

Damage Grade 4:
The large horizontal displacement of the upper storey of the building as well as the considerable inclination of the columns in the ground floor justify to classify the damage grade as 4.

Photo: FEMA, source: Kianirad, E. and O'Donnell, A., AIR Worldwide, Verisk, 2017: U.S. Earthquake Model Update Enhances View of Wood Frame Vulnerability: www.verisk.com/blog/u.s.-earthquake-model-update-enhances-view-of-wood-frame-vulnerability/

Fig. 4-67

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