ACCORD PARTIEL OUVERT
en matière de prévention, de protection et
d'organisation des secourcs contre les risques naturels
et technologiques majeurs du

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G. GRÜNTHAL

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EMS-98

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PREFACE TO THE 1st EDITION

It is an honour and particular pleasure for me to introduce this monograph devoted to the new "European Macroseismic Scale 1992", which was completed at the XXIII. General Assembly of the European Seismological Commission in Prague 1992.

It is legitimate to mention here that the ESC always paid great attention to the intensity classification of earthquakes. In 1964 the MSK-64 scale, named after its fathers V. Medvedev, W. Sponheuer and V. Karnik, was recommended by the ESC and widely used for almost thirty years in its basic form. However, a modified version of this scale was introduced in 1981.

Now, after more than five years of intensive work, we have in our hands an improved European Macroseismic Scale that embodies all the former achievements along this line. It is recommended by the ESC-General Assembly 1992 for general use within a three year test-period. This seems to be a useful and correct procedure in introducing an international standard by the ESC.

It is noteworthy that mainly the use of computer-based methods in the evaluation of macroseismic data finally lead to a better definition of the scale. It has to be understood that the intensity scale can only be improved by continuous discussion and using it in practice, but new ideas should not change the basic principles of the scale. The new scale presented here is a good example how to realise this difficult task.

Let me express my appreciation to the members of the ESC working group “Macroseismic Scales” and to all other colleagues who contributed to the present version. It is an excellent result of one of those long-term international projects, which are supported in first line by the ESC. I want to express my special thanks to the editor and WG-Chairman Dr. G. Grünthal, Potsdam, and to the other editors Dr. R.M.W. Musson, Edinburgh, Dr. J. Schwarz, Weimar, and Dr. M. Stucchi, Milan, for their tremendous efforts.

The ESC recognises the support of the Council of Europe through the Centre Européen de Géodynamique et de Séismologie in Luxembourg, the Swiss Reinsurance Co. in Zürich and the Bavarian Insurance Co. in Munich for hosting workshops. Our thanks are directed also to the board of the “Cahiers” for the edition of this volume.

Prague, March 8, 1993
Ludvik Waniek
President of the ESC

PREFACE TO THE 2nd EDITION

It is now five years since our late esteemed colleague, Ludvik Waniek, penned the Preface to the 1st edition of the European Macroseismic Scale. In these five years, much has happened in the development of the scale. The recommended three-year period of testing included the use of the new scale not only in a European context but in an international one, involving many of the most significant earthquakes of the period: Maharashtra 1993, Northridge 1994 and Kobe 1995 to mention but three.

In 1996 the 11th World Conference on Earthquake Engineering in Acapulco featured a special theme session on the scale and its testing and development. This is significant, given that the EMS is the first intensity scale designed to encourage co-operation between engineers and seismologists, rather than being for use by seismologists alone. Later that year, the XXV General Assembly of the ESC in Reykjavik passed a resolution recommending the adoption of the new scale within the member countries of the ESC.

The new scale, after much extra work to incorporate the lessons learnt during the testing period, is now complete, and I have much pleasure in presenting it to the seismological community with the hope that it will be adopted throughout Europe for future macroseismic investigations.

It remains only for me to thank Dr. Gottfried Grünthal, the responsible of the ESC Working Group "Macroseismic Scales", the editorial board, and all other colleagues who contributed to this important task, for the excellent work done. I would also like to thank again the Board of the Cahiers du Centre Européen de Géodynamique et de Séismologie for enabling the publication of this volume.

Trieste, 6 April 1998
Peter Suhadolc
Secretary General of the ESC

Contents

CONTRIBUTORS IN THE PROCESS OF ESTABLISHING THE EUROPEAN MACROSEISMIC SCALE (EMS)

The activities of the Working Group ’Macroseismic Scale’ of the European Seismological Commission ESC on ’Macroseismic Scale’ were initiated with the distribution of the Call for Proposals for Up-Dating the MSK Intensity Scale (being part of the ESC-Bulletin No. 3, March 1989) followed by the pamphlet ’Thoughts and Proposals for Up-Dating of the MSK Intensity Scale (ed. by the WG chairman **G. Grünthal**, Potsdam, Dec. 1989) where, in addition to participants of WG meetings, mentioned below, remarks were contributed by **P. Albini** (Milan), **N.N. Ambraseys** (London) and **A. Moroni** (Milan).

The participants of at least one of the meetings of the WG ’Macroseismic Scale’ (Zürich, 7-8 June, 1990; Munich, 14-16 May, 1991; Walferdange, Luxembourg, 16-18 March, 1992) have been: G. Grünthal, **V. Kárník** (Prague), **E. Kenjebaev** (Alma-Ata), **A. Levret** (Fontenay-aux-Roses), **D. Mayer-Rosa** (Zürich), **R.M.W. Musson** (Edinburgh), **O. Novotny** (Prague), **D. Postpischl** (Bologna), **A.A. Roman** (Kishinev), **H. Sandi** (Bucharest), **V. Schenk** (Prague), **Z. Schenková** (Prague), **J. Schwarz** (Weimar), **V.I. Shumila** (Kishinev), **M. Stucchi** (Milan), **H. Tiedemann** (Zürich), **J. Vogt** (Strasbourg), **J. Zahradník** (Prague), **T. Zsíros** (Budapest).

Contributions to WG-meetings were submitted moreover, e.g., by **R. Glavcheva** (Sofia), **R. Gutdeutsch** (Vienna), **A.S. Taubaev** (Almaty). The principal final lay-out of the European Macroseismic Scale EMS-92 was created by G. Grünthal, R.M.W. Musson, J. Schwarz and M. Stucchi in a meeting in Potsdam, 17-21 June, 1992 (for details cf. the Introduction to the previous version EMS-92). Comments to the published testing version EMS-92 were, e.g., submitted by: **J.A. van Bodegraven** (de Bilt), **J. Dewey** (Denver), **J. Grases** (Caracas), R. Gutdeutsch, V. Kárník, D. Mayer-Rosa, **A.A. Nikonov** (Moscow), **J. Rynn** (Indooroopilly), **H.-G. Schmidt** (Weimar), **L. Serva** (Roma), **N.V. Shebalin** (Moscow), **S. Sherman** (Irkutsk), **P. Stahl** (Pau), J. Vogt. The 11th World Conference on Earthquake Engineering, 23-28 June, 1996 featured a Special Theme Session on the Scale, especially on its engineering aspects, its testing and development, with presentations by J. Dewey, G. Grünthal, **C. Gutierrez** (Mexico), R.M.W. Musson, J. Schwarz and M. Stucchi.

The incorporation of the lessons learnt during the world-wide applications of the EMS-92 was maintained by the editorial board of the EMS-98; i.e., G. Grünthal, R.M.W. Musson, J. Schwarz and M. Stucchi, starting in 1996. Two meetings of the board were held in this connection (7-9 Nov., 1996 in Edinburgh, 26 Jan. - 1 Feb., 1998 in Potsdam). In preparation of the meeting in Edinburgh **M. Dolce** (Potenza), **C. Carocci** (Rome) and **A. Giuffré** (Rome) contributed with reference to the engineering aspects. The final stage of the work was supported by **D. Molin** (Roma), **A. Tertulliani** (Roma), **Th. Wenk** (Zürich), **H. Charlier** (Stuttgart) by submitting photographs illustrating damage degrees as well as by Th. Wenk with respect to joint efforts together with the editorial board on the engineering aspects incorporated into the present edition. Technical support was provided by **Ch. Bosse** (Potsdam).

INTRODUCTION

The purpose of this issue of the Cahier du Centre Européen de Géodynamique et de Séismologie is to present the update of the 1st edition of the European Macroseismic Scale (EMS-92) by the Working Group on Macroseismic Scales of the European Seismological Commission (ESC), which was published in Volume 7 of the Cahier in the spring of 1993.

This new scale was recommended by the XXIII General Assembly of the ESC in 1992 to be used in parallel with existing scales for a time period of three years, in order to gather experience under realistic conditions, especially on the more experimental parts of the scale: on the vulnerability classes and engineered constructions. This testing was not restricted to Europe. Several of the main earthquakes whose analysis was used for updating the EM-92 scale were: Roermond/The Netherlands 1992, Kilari/India 1993, Northridge/USA 1994, Kobe/Japan 1995, Aegion/Greece 1995, Cariaco/Venezuela 1997 and Central Italy 1997/98.

While the steps towards the creation of the first version of the EMS, edited in 1992, were summarised in the Introduction to that version, the general aims for introducing a new macroseismic scale will be given here in connection with an overview on the main innovations introduced for the EMS-98 with respect to the testing version EMS-92.

The basis for establishing the EMS was the MSK scale, which itself is an update relying on the experiences being available in the early 1960s from the application of the Mercalli-Cancani-Sieberg Scale (MCS), the Modified Mercalli scale (MM-31 and MM-56) and the Medvedev scale, known also as the GEOFIAN-scale, from 1953. Slight, barely noticeably changes to the MSK-64 were proposed by Medvedev in 1976 and 1978. At that time it became evident to many users that the scale needed several improvements, more clarity, and adjustment to incorporate newly introduced construction techniques. An analysis of the problems arising from the application of the MSK-64 scale was made by an Ad-Hoc Panel of Experts during a meeting in Jena in March 1980 (published in Gerlands Beitr. Geophys., 1981, where the earlier proposals by S.V. Medvedev were incorporated). The recommendations for changes of the scale from this group of experts were generally of a minor nature. This version served as the initial platform for the activities of the Working Group.

One of the main intentions for the creation of the new scale was not to change the internal consistency of the scale. This would result in intensity evaluations which would be different from earlier applications of the widely used twelve degree scales and which would require a reclassification of all earlier intensity assessments. This should be avoided at all costs. It would result in a complete confusion in all studies on seismicity and seismic hazard which depend heavily on macroseismic data.

Other general aspects considered to be fundamental to the updating were as follows:

- the robustness of the scale, i.e. minor differences in diagnostics should not make large differences in the assessed intensity; further to this, the scale should be understood and used as a compromise solution, since no intensity scale can hope to encompass all the possible disagreements between diagnostics that may occur in practice;
- such disagreements may also reflect differences in cultural conditions in the regions where the scale is used;
- the simplicity of the use of the scale;
- the rejection of any intensity corrections for soil conditions or geomorphological effects, because detailed macroseismic observations should just be a tool for finding and elaborating such amplification effects;
- the understanding of intensity values as being representative for any village, small town or part of a larger town instead of being assigned to a point (for one house etc).

The specific problems to be solved by the WG on Macroseismic Scales, on the basis of the above mentioned aspects, were:

- the need to include new types of buildings, especially those including earthquake-resistant design features, which are not covered by existing versions of the scale;
- the need to address a perceived problem of non-linearity in the scale arrangement at the junction of the degrees VI and VII (which, after thorough discussion for preparing the EMS-92, as well as for the EMS-98, proved to be illusory);
- the need to generally improve the clarity of the wording in the scale;
- the need to decide what allowance should be made for including high-rise buildings for intensity evaluations;
- whether guidelines for equating intensities to physical parameters of strong ground motions, including their spectral representations, should be included;
- to design a scale that not only meets the needs of seismologists alone, but which also meets the needs of civil engineers and other possible users;
- to design a scale which should be suitable also for the evaluation of historical earthquakes;
- the need for a critical revision of the usage of macroseismic effects visible in the ground (rock falls, fissures etc.) and the exposure of underground structures to shakings.

The term “macroseismic intensity” is used here entirely in the meaning of a classification of the severity of ground shaking on the basis of observed effects in a limited area.

The members of the WG are aware that the twelve-degree macroseismic scales are in fact ten-degree scales; i.e. intensity I (1) means nothing was observable and intensities XI and XII are, apart from their very limited practical importance, difficult to distinguish. If one takes into account the rare practical use of the intensities II and XI as well as the fact that intensity XII defines maximum effects, which are not to be expected to occur in reality, the result is even an eight-degree scale. But, as mentioned above, to avoid any confusion, the classical numbering is kept.

Serious problems arose with the treatment of engineered or antiseismic constructions for intensity evaluation. Reasons for these were:

- the limited knowledge and experience up to now on the systematics of earthquake damage patterns for this category of buildings;
- the great variety of systems for classifying engineered constructions in seismic codes;
- disagreements between engineers and seismologists in the use of intensity and related research topics (e.g. a tendency among engineers to overestimate the importance of instrumental data in connection with intensities and therefore the danger to overcharge the concept of intensity);
- the often imprecise seismological approach to intensity assignment with regard to building types previously used in the MSK-64 or in the MM-56 scales; i.e. the general neglect of the quality of workmanship, the structural regularity, the strength of materials, the state of repair, and so on, as well as the need to consider such features as scaling conditions.

It was accepted already for the EMS-92 that engineered buildings can be used for intensity assignment only on the basis of earthquake-resistant design principles. An essential step for overcoming these problems was the introduction of the Vulnerability Table which provides the possibility to deal in one scheme with different kinds of buildings and the variety of their actual ranges of vulnerability. In former scale versions building types were defined in a rather strict way, by construction type alone. This vulnerability table, as an essential part of the EMS, incorporates engineered and non-engineered buildings into a single frame. It was clear from the beginning that the EMS-92 version with its adopted compromises had to be understood as an experimental or tentative solution, connected with the commitment to gather more information and experience on this subject, in order to become able to introduce necessary improvements. A period of three years was stipulated for this. Users of this version were kindly requested to submit their comments for further improvements to the chairman of the Working Group "Macroseismic Scales".

At the final stage of the anticipated three years testing period of the EMS-92 and after applications throughout the world it became clear that the personal judgement used in assigning intensity can be decreased with the new scale. This does not mean that assessing intensity with the new scale is easier in every case - but users become aware of problematic cases in a more direct way. The introduction of the vulnerability table was highly acknowledged, as well as the introduction of the new definitions of damage grades and especially the Guide to the Use of the Intensity Scale and the different Annexes. New building types or those which are not covered by the present vulnerability table can be added in an appropriate way. Generally, the engineering aspects incorporated into the new scale were appreciated by the engineers. They were the subject of sessions at international conferences on earthquake engineering, and even of a Special Theme Session on the EMS-92 at the World Conference on Earthquake Engineering in Acapulco in 1996. The new elements of the EMS in the form of the vulnerability table and the damage grades have facilitated the use of the scale by insurers, planners, and decision makers to derive damage or risk scenarios for given intensities. Criticism has been expressed mainly on the downplaying of the role of effects in natural surroundings in the intensity assignment. The applications of the EMS-92 made clear that only its tentative parts, i.e., the use of engineered buildings, needed significant modification.

The XXV General Assembly of the ESC in Reykjavik, 1996, passed a resolution recommending the adoption of the new macroseismic scale within the member countries of the European Seismological Commission, considering that additional effort had to be invested to overcome several inconsistencies in the use of engineered structures.

While studies of the structural pattern of several earthquakes, e.g. Northridge/USA 1994, Kobe/Japan 1995, Aegion/Greece 1995, were going on, several other damaging events, like Dinar/Turkey 1996, Cariaco/Venezuela 1997 and Central Italy 1997/98, provided further information and experience. They led finally, though with no complete agreement, to modifications of the vulnerability table with respect to reinforced structures (RC), their level of earthquake resistant design and their differentiation into RC wall and RC frame structures, as well as to the introduction of steel structures. The wording of the classifications of damage grades were in parts newly structured. Damage to buildings as part of the definitions of intensity degrees have been more clearly arranged.

The former Annexes of the EMS-92 were incorporated into the new section of the EMS-98 entitled Guidelines and Background Materials. The editors are aware of the sometimes strong differences in character of several of its sub-sections. The old Annexe B on engineered structures was subject to major changes. These aspects are now mainly treated within the sub-section Vulnerability, and are now better integrated with the scale as a whole. Parts of the former Guide have been modified, supplemented and re-arranged. Most of the photographs of the former Annexe A illustrating classifications of vulnerability and damage grades were replaced by other examples from Europe and Japan. The comments are now restricted to types of structures and damage grades, since a separate set of examples would be needed to illustrate vulnerability. The previous examples (formerly Annexe D) have been supplemented by one presentation assigning intensity from early historical materials. The restrictions and arguments on how effects on natural surroundings (formerly Annexe C) can be incorporated into macroseismic practice were revised in the light of new research. According to frequently expressed wishes a short form of the EMS-98 was created (sub-section 8). Although clearly stated at the beginning of the short form that it is not suitable for intensity assignments, there is a danger of its misuse in this way. This short form is included for educational purposes, e.g., at schools or by the mass media, or otherwise to give a brief explanation of the significance of the numbers of the scale to an audience unable to digest the full version.

It is beyond the scope of the introduction to deal with all the “ifs” and “buts” which unavoidably arose during the process of updating, both for the EMS-92 and the EMS-98. It was necessary in each step of the work to find the right balance between the aimed consistency of the updated version with the original scale and several obviously excellent ideas for improvement of the scale which were going beyond the goal defined for the WG activities. Some of these points are mentioned in the section Guidelines and Background Materials (e.g. the problem of the correlation of intensities with strong ground motion parameters). Others could be subject of further activities. One of them will doubtless be the introduction of formalised procedures (or algorithms) for computerised macroseismic intensity evaluation. It has to be stressed that it was not an aim of the WG to create such algorithms - only to create the basis for them, i.e. to present updated, as clear as possible, qualitative, descriptive definitions of what the different intensities should actually stand for.

The whole process of establishing first the EMS-92 and finally the EMS-98 went on for almost ten years - including several long lasting breaks, which were essential for gathering further experiences. The given version of the EMS should represent a subsequent final stage of these activities in the scale’s updating. Further macroseismic practice may enable a deeper insight into the complex matters of assigning intensity. Future applications or future needs might be the basis for further improvements of this new tool in the seismological and engineering practice for classifying the effects of earthquakes on humans, on objects in the human’s environment, or on buildings as an essential element of the human society.

MACROSEISMIC INTENSITY SCALE

Classifications used in the European Macroseismic Scale (EMS)

Differentiation of structures (buildings) into vulnerability classes (Vulnerability Table)

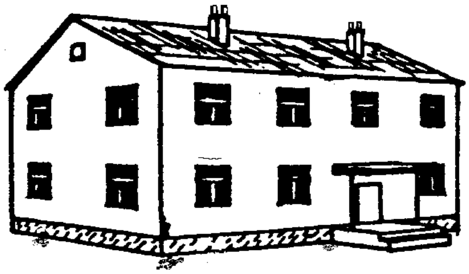
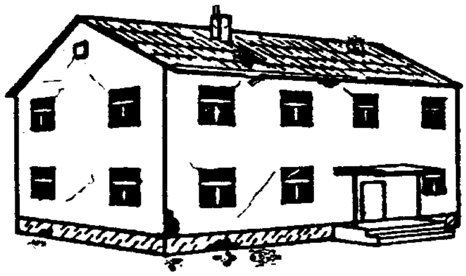
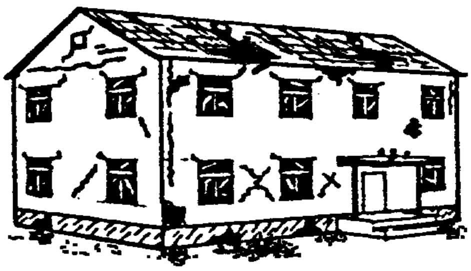
	Type of Structure	Vulnerability Class A	B	C	D	E	F
MASONRY	rubble stone, fieldstone	O					
	adobe (earth brick)	O	—				
	simple stone	···	O				
	massive stone		—	O	···		
	unreinforced, with manufactured stone units	···	O	···			
	unreinforced, with RC floors		—	O	···		
	reinforced or confined			···	O	—	
REINFORCED CONCRETE (RC)	frame without earthquake-resistant design (ERD)	···	—	O	···		
	frame with moderate level of ERD		···	—	O	—	
	frame with high level of ERD			···	—	O	—
	walls without ERD		···	O	—		
	walls with moderate level of ERD			···	O	—	
	walls with high level of ERD				···	O	—
STEEL	steel structures			···	—	O	—
WOOD	timber structures		···	—	O	—	

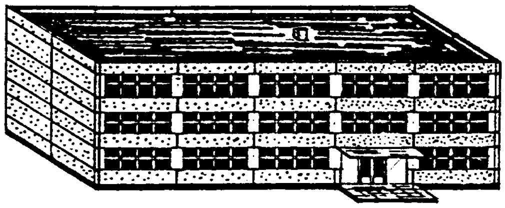
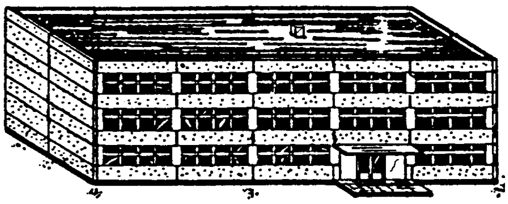
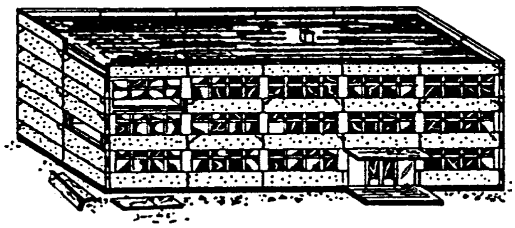
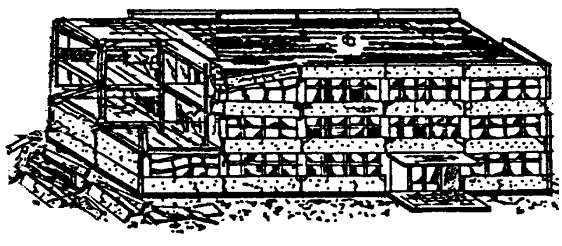
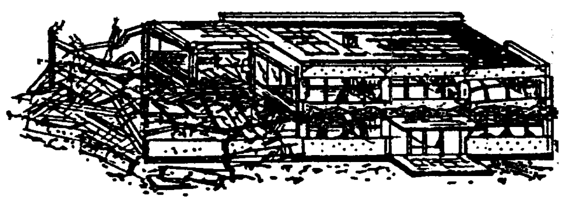
O most likely vulnerability class; — probable range;
····· range of less probable, exceptional cases

The masonry types of structures are to be read as, e.g., simple stone masonry, whereas the reinforced concrete (RC) structure types are to be read as, e.g., RC frame or RC wall.
See section 2 of the Guidelines and Background Materials for more details, also with respect to the use of structures with earthquake resistant design.

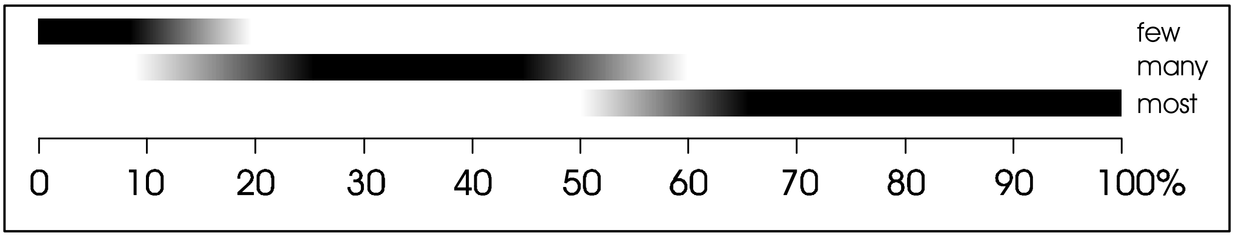
Classification of damage

Note: the way in which a building deforms under earthquake loading depends on the building type. As a broad categorisation one can group together types of masonry buildings as well as buildings of reinforced concrete.

Classification of damage to masonry buildings	
	**Grade 1: Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very 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 individual non-structural elements (partitions, gable walls).
	**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.

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 frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage** **(slight structural damage,** **moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual 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 reinforced 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.

Definitions of quantity



Definitions of intensity degrees

Arrangement of the scale:

a) Effects on humans
b) Effects on objects and on nature
   (effects on ground and ground failure are dealt with especially in Section 7)
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 at isolated instances (<1%) of 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 felt outdoors only by very few. 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 etc.
b) China, 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. China 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 window panes 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 class 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 class A and B; a few of class 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. Objects like TV sets, typewriters etc. fall to the ground. Tombstones may occasionally be displaced, twisted or overturned. Waves may be seen on very soft ground.
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. Waves are seen on soft ground.
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 class A, B and practically all of vulnerability class C are destroyed. Most buildings of vulnerability class D, E and F are destroyed. The earthquake effects have reached the maximum conceivable effects.

GUIDELINES AND BACKGROUND MATERIAL

1 Assigning intensity

1.1 The nature of intensity

As stated in the introduction to this scale, intensity is here considered a classification of the severity of the ground shaking on the basis of observed effects in a limited area. Intensity scales, and the concept of intensity itself, have been evolving through the course of this century. 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). To describe intensity in this way is useful in representing 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 things that may be found in an everyday environment. These things can be considered as sensors, since their response to the shaking is used to measure the strength of the shaking. But they are not items of special equipment that have to be deployed by the investigator – because they are part of the normal environment, these sensors are extremely common. This is one of the great 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) are frightened by it.

Ordinary objects. As intensity increases, greater numbers of ordinary domestic items (crockery, books, etc) begin to shake and then be 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 cracks in embankments, rockfalls, and so on.

The European Macroseismic Scale (EMS-98) concentrates chiefly on the first three of these four groups. The fourth is considered to be less reliable, as is explained in Section 7.

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 strength of shaking.

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

The EM-98 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 strength of the shaking. Earlier scales often described only effects, with no quantities, implying that the same effect was universal on all such sensors when the intensity reached that value.

1.2 The structure of the EM-98 intensity scale

The EM-98 intensity scale, like the MSK scale which preceded it, is one of a family of intensity scales which originated with the widely used simple ten degree scale by Rossi and Forel; this was revised by Mercalli, subsequently expanded by Cancani to twelve degrees, and then defined in a very full way by Sieberg as the Mercalli-Cancani-Sieberg (MCS) scale. It is this scale which forms the starting point not only for the MSK/EM-98 scale, but also for the numerous versions of the "Modified Mercalli" scale. 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 EM-98 scale and other intensity scales is in the detail with which different terms used are defined at the outset, in particular, building types, damage grades, and quantities, and these are now considered individually. Also, the European

Macroseismic Scale is the first intensity scale to be illustrated. Drawings show graphically precisely what is meant by the different damage grades, and the example photographs in Section 5 can be used in the field for comparison with actual cases of damaged structures. The use of these illustrations is intended to improve the standardisation between individual practitioners in the use of the scale. Similarly, the addition to the scale of these guidelines (another 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 damage to buildings of a particular type would be grouped together irrespective of the strength of the building damaged. 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 European Macroseismic Scale incorporates a compromise, in which a simple differentiation of the resistance of buildings to earthquake generated shaking (vulnerability) has been employed in order to give a robust way of differentiating the way in which buildings may respond to earthquake shaking. The Vulnerability Table is an attempt to categorise in a manageable way the strength of structures, 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 scale, and this was also used in the MSK scale in 1964. This subdivision is not made out of architectural interest; it represents, very crudely, 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 block. It is clear, though, that the condition of a building, and also other factors besides building construction type, also affects its vulnerability.

In the opinion of the authors of the EM-98 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 EM-98 scale in order to make explicit what was already being used as best practice.

This is done graphically in the Vulnerability Table. For each building type, this table gives a line showing the most likely vulnerability class(es) for it, and also the probable range (shown as a dashed line where this is uncertain). The position along this line has to be found by taking into account other factors such as state of disrepair, quality of construction, irregularity of building shape, level of earthquake resistant design (ERD) and so on. This is discussed in more detail in Section 2.

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 strength 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 operator. One should also note that not all possible combinations of vulnerability class and damage grade are mentioned for each degrees 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 (see Section 4.6).

A point which has not been made in previous versions of the scale is that different types of building respond and fail in different ways, and this has been addressed in the present version by giving separate, illustrated accounts of damage to both masonry and reinforced concrete buildings. 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 or curtain walls). In the special case of buildings with ERD one must also distinguish damage in special (and therefore provided) plastification zones (such as coupling beams in wall structures, joints in buildings of prefabricated wall elements or beams in joints of frame structures).

It is advisable to examine buildings both inside and out, as outward appearances may be misleading (although sometimes it is difficult to do this for safety reasons).

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, and liquefaction. By contrast, damage which is greater than expected due to such factors as resonance conditions, or the strength of the seismic load 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 intensity. In particular:

a) Structures designed against an earthquake of low intensity, to be expected with high probability of occurrence, should sustain such an event without structural damage and with no damage, or only minor damage, that could affect the serviceability.
b) Structures designed against an earthquake of medium intensity, to be expected with low probability of occurrence, are explicitly allowed to react under the design earthquake with slight non-structural damage, but should survive without loss of serviceability
c) Structures designed against an earthquake of high intensity have to sustain structural damage without loss of structural integrity and stability. For this level of design earthquake damage is permitted but should not exceed grade 3.

Consequently there may be a saturation of damage at grades 2 and 3. According to the results of damage surveys this might require in some cases the differentiation of vulnerability classes depending on intensity, i.e. engineered structures with ERD tend to belong to higher vulnerability classes with increasing intensity.

One should be very much aware that when investigating the damage effects caused by an aftershock the buildings may have been much 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. 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 a given 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 not 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 European town. Thus 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 he makes in particular cases.

It is also desirable to assign values to locations which are reasonably homogeneous, especially with regard to soil types, otherwise the range of shaking effects reported 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 under 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.

While 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 data he has. 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.

Sometimes it is not possible to make a definite assignment of intensity and only a range of values can be given. This is discussed in more detail in Section 4.5.

The photographs in Section 5 may be used to help in assessing damage grades. In addition, several examples of intensity assignment are presented in Section 6, "from documentary data" and "from questionnaire data". These examples are not intended to be models to be followed rigidly, but rather as illustrations of the processes of evaluation that can be used.

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 EMS. 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 the report had read only, "a very frightening earthquake at Slavonice", 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 a number of 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 high buildings. It is well-known that 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 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 higher than the fifth floor when assigning intensity; although in practice the actual behaviour of individual buildings will vary considerably, especially dependent on the slenderness 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 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 datum is typical of intensity 2.

As well as the height of buildings, their symmetry and regularity also influences the way they behave in an earthquake (see Section 2). 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 will withstand earthquake shaking.

Observations from special structures, such as lighthouses, radio towers, bridges, etc., should not be used; the same is true normally of monumental buildings (such as cathedrals), but see Section 3.5. Data from observers underground are also not easily comparable with observations made at the surface and should not be used.

1.8 Effects of soil conditions

Absolutely 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. It should not be glossed over. 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 Roman or Arabic numerals may now be considered a matter of taste.

There also exist sets of conventional symbols for plotting intensities, based on circles in which an increasing amount is filled in with higher intensity values.

2 Vulnerability

The word "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 it can be said that the 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 word "vulnerability" in other contexts. The following discussion illustrates how the term is applied in the EM scale, with the principal aim of demonstrating how vulnerability class is to be assessed.

2.1 Building vulnerability in intensity scales - a 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 massive 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 strength of shaking required to throw a typewriter 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 a good discrimination between different strengths 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 Modified Mercalli scale in its 1956 formulation by Richter, or the MSK scale in 1964, had to address the issue carefully. They did so by dividing buildings into different classes on the basis of building type, that is, the construction materials employed for the lateral load resisting system. In this, building type was used as a simple analogue for vulnerability.

This is an important point to make. It might be thought that the explicit treatment of building vulnerability in the EM scale represents a substantial innovation. In fact, it is in direct continuity with the MSK and MM 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, it was realised in the time since those scales were formulated, that the simple use of building type as a vulnerability analogue is insufficient. In the first case, variations of strength within any one type of building have been found often to be just as great as those between different building types, and this has led to a number of problems in assigning intensity. In the second case, such a system is relatively inflexible when it comes to adding new types of building.

2.2 Building types and the Vulnerability Table

The MSK scale defined building classes by type of construction as a simple attempt to express the vulnerability of buildings. In the EM scale, it has been attempted to move closer to classes directly representing vulnerability. Accordingly, six classes of decreasing vulnerability are proposed (A-F) of which the first three represent the strength of a "typical" adobe house, brick building and reinforced concrete (RC) structure, i.e. they should be compatible with building classes A-C in the MSK-64 and MSK-81 scales. Classes D and E are intended to represent approximately linear decreases in vulnerability as a result of improved level of earthquake resistant design (ERD), and also provide for well-built timber, reinforced or confined masonry and steel structures, which are well-known to be resistant to earthquake shaking. Class F is intended to represent the vulnerability of a structure with a high level of earthquake resistant design, i.e. a structure of the highest earthquake resistance due to the incorporated design principles.

In assessing the vulnerability of an ordinary structure in the field, the first step is obviously to assess the building type. This provides the basic vulnerability class. The most common building types in Europe are each represented by an entry in the Vulnerability Table showing the most likely classification in terms of vulnerability class as well as the range that may be encountered. The building types in the Vulnerability Table are classified by their main groups: masonry, RC, steel and wood, and these are discussed in more detail below.

The vulnerability table includes entries for most of the major building types encountered in Europe. For reasons of space, the listing of types is necessarily simplified. It is recognised that the table is incomplete, in that some building types (e.g. adobe, wood) would benefit from further sub-classification. Some basic ideas on introducing new building types are given in Section 2.5; but this is not a task to be entered into lightly.

2.2.1 General remarks on earthquake resistance

In the construction of the Vulnerability Table the principal partition is made in terms of construction type. However, when considering in a general way the topic of the earthquake resistance of buildings, one can also consider a progression in terms of design features.

At the lowest level are buildings without earthquake-resistant design (ERD). Such buildings include both engineered and non-engineered construction. 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 in a recommendatory manner. Only buildings at this level have ever been considered by previous intensity scales.

At the second level are buildings with ERD, i.e. buildings designed and built according to the scope of codes. Some design philosophy has been followed, including the processes of seismic hazard assessment and the construction of a zoning map with parameters describing the expected seismic action for different seismic zones. Buildings of this sort can be expected in earthquake regions where the design of buildings has to take into account earthquake resistant regulations. Such buildings may include masonry constructions as well as RC or steel buildings. Buildings at this level are addressed by this scale for the first time.

At the highest level are buildings with special antiseismic measures, such as base isolation. These behave in a special manner under seismic loading, typically taking no damage unless the base isolation process fails in some individual way. Buildings at this level cannot be used for intensity assignment at all.

Engineered structures with modern structural systems, not designed against lateral seismic loads, 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 inherent earthquake resistance. Well-built (non-engineered) wooden or masonry structures can behave in a fashion comparable to buildings with ERD typical for vulnerability class D and exceptionally E. This may also apply to buildings to which special strengthening measures have been applied (retrofitting). In such cases, even field stone structures with good strengthening measures can behave well above their normal vulnerability class.

It should be noted that, for simplicity, reinforced concrete structures without earthquake resistant design (ERD), and those with a low level of ERD, are summarised as one building type, since they behave generally in a similar way. The typical (most likely) vulnerability class of such buildings is C. This is not to discount entirely the usefulness of a low ERD level, which is shown shiefly in mitigating very poor cases. RC structures with a low level of ERD descend to class B only in a few exceptional cases, while similar structures with no ERD can easily be equated to class B and in exceptional cases to class A.

The importance of horizontal elements in determining the performance of buildings under earthquake loading has often been neglected in the past, at least with respect to masonry structures. The strength of the floors of a building, or other horizontal stiffening elements, often plays a key role in deciding the vulnerability of a structure. One should note that it may be difficult or impossible to determine from the outside of a building what sort of floors or horizontal elements are present; it is very important to be able to examine the inside of the building as well, if at all possible, in order to assess the vulnerability correctly when in the field.

2.2.2 Masonry structures

2.2.2.1 Rubble stone/fieldstone

These are traditional constructions in which undressed stones are used as the basic building material, usually with poor quality mortar, leading to buildings which are heavy and have little resistance to lateral loading. Floors are typically of wood, and provide no horizontal stiffening.

2.2.2.2 Adobe/earth brick

This type of construction can be found in many places where suitable clays can be found. Methods of adobe construction vary widely, and this introduces some variations in the strength of adobe houses against earthquake shaking. Walls built up of layers of adobe without the use of bricks are stiff and weak; brick houses may perform better depending on the quality of mortar, and, to a lesser extent, the quality of the brick. The weight of the roof is one of the most important factors in the performance of such houses, heavy roofs being a liability. Adobe houses with wooden frames possess added strength and perform significantly better. Such buildings may suffer damage to the walls relatively easily, while the wooden frame remains intact due to its higher ductility. One also encounters cases where unconnected wooden beams and columns are used in adobe houses; these provide extra horizontal stiffness and therefore improve performance, but not so much as a connected frame would do.

The type of housing encountered in some parts of Europe known as "wattle and daub", where a wooden frame is filled in with laths covered with clay, is similar to adobe/wood construction.

2.2.2.3 Simple stone

Simple stone construction differs from fieldstone construction in that the building stones have undergone some dressing prior to use. These hewn stones are arranged in the construction of the building according to some techniques to improve the strength of the structure, e.g. using larger stones to tie in the walls at the corners. In the normal case, such buildings are treated as vulnerability class B, and only as class A when in poor condition or put together with particularly poor workmanship.

2.2.2.4 Massive stone

Buildings with very large stones are usually restricted to monumental constructions, castles, large civic buildings, etc. Special buildings of this type such as cathedrals or castles would not normally be used for intensity assessment for reasons given in Section 2.3.5. However, some cities contain areas of 19th century public buildings of this type which could be used for intensity assessment. These buildings usually possess great strength, which contributes to their good vulnerability class (C or even D for exceptionally well-built cases).

2.2.2.5 Unreinforced brick/conrete blocks

This very common type of construction is the archetypal "B" type of building in the original MSK scale against which others can be measured. In Eurocode 8 such construction is referred to under the heading of “manufactured stone units”. Its very commonness means that 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 for the wealthy, or built in locations where lateral resistance is needed for resisting wind loading. It is characteristic of this 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.

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

2.2.2.6 Unreinforced brick with RC floors

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 brick but the floors are reinforced concrete, will behave significantly better than normal brick construction. 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.

2.2.2.7 Reinforced brick and confined masonry

Under this heading are found various systems in which significant effort has been made to improve the performance and ductility of masonry construction. 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. Confined masonry is characterised by masonry built rigidly between structural columns and beams on all four sides, and provides a similar level of resistance. It is not intended in such cases that the connecting elements should perform as a moment resistant frame, where masonry in most cases would only act as non-structural infills. In certain regions special stone systems are developed where shaped (e.g. interlocking) building stones are formed out of concrete; these also perform very well. Another efficient system is known as grouted masonry, comprising walls consisting of an outer and inner brick shell, connected with an concrete core vertically and horizontally reinforced. In this case, problems can arise if the bond is weak and/or the shells are improperly connected. The overall performance of such systems should also be equivalent to reinforced masonry, although experience with this form of construction is limited at present.

2.2.3 Reinforced concrete structures

This type of construction, so common in modern cities, varies extremely in appearance, design and strength, making it difficult to present a simple guide as to how to deal with such structures. In the Vulnerability Table a division is made on the level of earthquake-resistant design; how this should be applied is discussed in Section 2.3.8.

2.2.3.1 Reinforced concrete frame structures

The structural system of reinforced concrete frame structures consists of beams and columns which form a frame and which are coupled by monolithic moment- and shear resistant beam-column-joints. RC frame structures resist both vertical and lateral loads. The behaviour of RC frames is determined by the ratio between the column's height and beam's length as well as the resistance (cross-sections) of columns and beams. Weak columns and strong beams indicate a vulnerable system against lateral loads. RC frame structures are very common and wide-spread, but should be regarded as the building type with the largest scatter of earthquake resistance. In some cases the vulnerability is comparable to adobe or simple stone buildings leading to misleading (high) intensity assignment if the vulnerability class is taken for the most likely class from the Vulnerability Table neglecting the probable range and exceptional cases. Failure of RC frame buildings often leads to spectacular damage cases. Damage observed during past earthquakes provide experience about typical design defects and reasons for the repeatedly reported damage pattern. Differences in the stiffness and resistance of the structural system with respect to the transversal and longitudinal direction should be avoided. As an indication for the weakness in one (probably the longitudinal) direction the user should consider the ratio of width and height of columns cross-section as well as the coupling between (transversal) frames.

In most practical cases the structural systems can be described as RC frames with masonry infills. The possible interaction between RC frame and brittle infills can contribute to a more vulnerable system. Due to this interaction columns and joints have to react to the additional loads they are, in general, not designed for. If the infill has openings or has other discontinuities a “short-column” effect is predetermined resulting in shear failure of columns (diagonal cracks with tilting of column reinforcement). This is again an indication for a vulnerable building type and even in cases where one should assume a certain code-consistent level of ERD this is an indication that the final (actual) ERD tends to be below the most likely one.

For RC frames (but also steel and timber frames) earthquake resistant design is connected with a particular damage pattern. Damage zones should be provided for the end-beam joints. No damage is allowed for the columns or the beam-column joints. Nevertheless, in general the damage is still concentrated in columns. If the concrete cover is detached one should check the reinforcement with respect to the spacing of stirrups which should be limited in all critical zones. Such details of reinforcement provide an impression of the inherent design features and the final (actual) level of ERD.

The seismic vulnerability of RC frames is affected by all the factors, previously mentioned like regularity, quality and workmanship or ductility. RC frames are particular vulnerable against interruptions of lateral stiffness over the building height. A soft ground floor can result into the collapse of the entire building. Such building types are very vulnerable against lateral loads. If the buildings have irregularities in the ground-plan, the damage will be concentrated at places which are far from the stiffness center, i.e. if some outer 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 not be neglected when assigning the most appropriate vulnerability class.

2.2.3.2 Reinforced concrete wall structures

Reinforced concrete wall structures are characterised by in general vertical elements supporting other elements and having an elongated cross-section with a length to thickness ratio greater than 4 and/or partial-section confinement. If two or more walls are connected in a regular pattern by coupling beams the structural systems is called 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. The vulnerability is affected by large openings and discontinuities of walls and their geometrical shape over the building height as well as interruptions within the ground floor (creating a soft storey).

RC wall structures are characterised by a higher 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 even in the case of uniform outer view which might contribute to exceptional cases of vulnerability.

Contrary to RC frames RC walls tend to behave within a smaller range of vulnerability classes. According to the Vulnerability Table exceptional cases are restricted to the vulnerability class B (without ERD) and vulnerability class C for walls with ERD. There are several structural systems which are composed by spatial frames and structural walls (so called dual systems) or by a system of flexible frames combined with walls concentrated near the centre or symmetrically arranged in one direction of the building (so called core systems). Core systems are considered to behave in a less ductile manner than frame, wall or dual systems.

2.2.4 Steel structures

Under this heading come buildings for which the main structural system is provided by steel frames. From existing macroseismic evaluations, only a few data for steel frame structures are so far available, but these indicate a high level of earthquake resistance. 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 level of earthquake resistance, and therefore on the most appropriate vulnerability class, should take into account the stiffening system as well as the type of joint connections. The ductility of the entire system is determined by the lateral resisting system (i.e. the frame type and kind of bracing). For steel frame buildings without special antiseismic measures or 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 shear walls/core, or frames with eccentric or X- or V-bracing provide lateral resistance and ensure a ductile behaviour. Vulnerability class E can be considered as the most likely vulnerability class. In case of an improved level of ERD the vulnerability class F can be regarded as probable. The probable vulnerability classes for moment-resisting steel frame structures are depending on the level of ERD as discussed in Section 2.3.7.

2.2.5 Wooden structures

Wooden buildings are given relatively brief treatment since they are not so often encountered in the more seismically active parts of Europe. The innate flexibility of wooden construction gives them a high resistance to damage, though this can vary considerably as a function of condition. Loose joints or rotten wood can make a wooden house quite vulnerable to collapse; it was notable in the case of the Kobe earthquake of 1995 that traditional wooden houses in parts of the city performed very badly on account of poor condition. This was a very good example of how vulnerability depends on something quite other than building construction type.

The structural system providing lateral resistance should be considered carefully. 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. This type of timber structure is typically represented by vulnerability class C, and should be distinguished from timber frame structures which are resistant against lateral loads caused by earthquake shaking. The ductility of wooden structures depend on the ductility of the connections.

Some improvements should be made in the future to the way in which wooden structures are handled by the scale. These should include making some subdivision of wooden structures into different groups, and addressing in detail the stages of damage to wooden buildings which are not described in the definitions of damage grades in the scale in the way that they are for masonry and RC structures.

2.3 Factors affecting the seismic vulnerability of buildings

There are a number of different 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 .

2.3.1 Quality and workmanship

It must seem common-sense to say that a building which is well-built will be stronger than one that is badly built, yet this has not been previously taken into consideration in intensity scales, no doubt partly because of the difficulty of defining what constitutes "good" and "bad". Even to leave discrimination of these conditions on a subjective basis is better than discounting them altogether. The use of good quality materials and good construction techniques will result in a building much better able to withstand shaking than the use of poor materials and slipshod workmanship. In the case of materials, the quality of the mortar is particularly important, and even rubble masonry can produce a reasonably strong 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 actually fails to meet the provisions of the appropriate seismic building code.

2.3.2 State of preservation

A building which has been well-maintained will perform in accordance with its expected strength 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 good repair.

2.3.3 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).

With respect to current code developments (i.e. Eurocode 8) engineered buildings have to be classified according to their structural regularity on the basis of both global parameters (dimensions, ratios of geometry) and global and local deviations from a regular ground plan and vertical shape. These considerations are equally applicable to non-engineered structures. Regularity should be considered in a global sense, i.e. regularity is more than just external symmetry in plan and elevation. Regularity in the sense of this scale includes both the natural characteristics of a building and, for engineered structures, also measures taken within it to ensure a simple or, to a limited extent, controlled behaviour under seismic action. For engineered structures it is expected that measures taken to ensure regularity corresponds with rules of earthquake resistant design.

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 noteworthy 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 collapse. 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.

2.3.4 Ductility

Ductility is a measure of a building's ability to withstand lateral loading in a post elastic range, i.e. by dissipating earthquake energy and creating damage in a controlled wide spread or locally concentrated manner, depending on the construction type and structural system. Ductility can be a direct function of construction type: well-built steel houses have high ductility, and therefore resist shaking well, compared to more brittle lower-ductility buildings such as brick houses. In buildings designed against earthquakes, the parameters of the building determining dynamic characteristics (stiffness and mass distribution) will be controlled; and quality of energy transformation and dissipation should be ensured by coupling between ground, foundation and structural elements and by avoiding critical local concentrations of damage (fracture).

2.3.5 Position

The position of a building with respect to other buildings in the vicinity can affect its behaviour in an earthquake. 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 natural 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 strength of earthquake shaking as such and should be discounted in assigning intensity.

2.3.6 Strengthening

Where measures have been taken to retrofit buildings in order to improve them against earthquakes, the effect is to create what are practically new, compound, building types. These can differ radically in performance from the basic, unmodified building. For example, taking old fieldstone constructions and improving the horizontal elements by replacing the floors or inserting ties can improve the performance up to class B. If in addition to this, mortar or epoxy injections or RC jacketing is applied, the performance can improve into the classes assigned to buildings with ERD.

2.3.7 Earthquake resistant design (ERD)

For the purpose of a macroseismic scale it is impossible to give a complete classification of engineered buildings, reflecting differences and refinements within national seismic codes. Correlations between levels of earthquake resistance according to seismic codes in European or other countries and typical vulnerability classes provided have to be developed and require a discussion among national specialists. Vulnerability functions for different types of structures should be evaluated for engineered structures primarily based on the intended (code-consistent) level of earthquake-resistant design. 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 in any country or region. The actual vulnerability class will be assigned with respect to the final (actual) level of ERD, which may differ (although it should not in most cases) from the code-consistent level, due to other factors.

2.3.7.1 Code-consistent ERD

Assuming that buildings in an earthquake zone i are designed and built for a design earthquake of the intensity (or ground motion), matching site and subsoil conditions of the zone i, engineered buildings are classified according to the incorporated level of earthquake-resistant design (ERD). The earthquake-resistant design is governed by national seismic codes.

The level of earthquake-resistant design can be distinguished on the basis of design parameters (intensity, peak ground motion, base shear) which are directly related to the seismic zone i. Therefore, it is possible to predict the code-consistent level of ERD and with this to evaluate the ERD-i type(s) of engineered buildings in the study area on the basis of the seismic zone defined within the national seismic building code. It can be assumed that for buildings the type ERD-i can be specified, where i is an expression for the intensity of the design earthquake as well as for the level of earthquake resistance.

Commonly, each region or town is characterised by one ERD-i type only; but for the assignment of intensity it is necessary that information is available which indicates the distribution or individual sites of those buildings. A region or town can be characterised by different ERD-i types when buildings are present which were built according to different seismic codes.

Three types of ERD-i can be classified as follows:

Type ERD-L: Engineered buildings incorporating a low or minimum level of earthquake-resisistant design

This level is characterised by the limitation of structural parameters (and in some cases a simplified method of calculation). Depending on the importance of the building it may be permitted to ignore additional seismic loads. Special measures of detailing (to improve ductility) are not typical for this building type. This type is widespread in areas of low or moderate seismicity. (Commonly, buildings of this type are designed for an intensity of 7 or a base shear coefficient of 2-4 % g.) Engineered buildings incorporating (because of their regularity and quality of workmanship) a limited or equivalent level of earthquake-resistant design are comparable to this type of ERD. Therefore, RC structures without ERD and those RC structures of Type ERD-L are considered to belong to one building group in the Vulnerability Table.

Type ERD-M: Engineered buildings incorporating a moderate (improved) level of earthquake- resistant design.

This level is characterised by the realisation of design rules. Special measures of detailing (to improve ductility) are partially implemented. This type is to be expected in areas of moderate to high seismicity. (Commonly, buildings of this type are designed for an intensity of 8 or a base shear of about 5-7 % g.)

Type ERD-H: Engineered buildings incorporating a high (qualified) level of earthquake-resistant design.

Here, seismic loads are calculated by dynamic methods. 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 seismicity. (Commonly, buildings of this type are designed for an intensity of 9 or a base shear of about 8-12 % g). This level is not commonly reached or required in European countries, and should be characterised by improved ductility of structural systems and controlled mechanisms of plastification as a result of special antiseismic measures (capacity design).

The level of earthquake-resistant design 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.

2.3.7.2 Importance

With respect to code developments the importance of engineered buildings has to be taken into account because it can contribute to different levels of earthquake-resistant design (ERD) for the same building type. 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.

The classification of importance is not harmonised and is also quite different in different European earthquake regulations, and is connected with the definition of seismic load amplifying factors (importance factors). In special cases buildings of higher importance are designed for loads which are typical for a higher zone or intensity class. Buildings of high importance or higher risk potential should be carefully considered with respect to the final level of design loads. In general, a higher level of ERD should be assumed for this kind of buildings.

2.3.7.3 Final (actual) level of ERD and vulnerability class

After the code-consistent level has been determined, it is then necessary to find the appropriate (or actual) level of ERD and to determine the vulnerability class. This involves consideration of the level of regularity as well as of the quality or workmanship of the different building types or structural systems, and the implementation of modern design principles in the study area. Furthermore, it is necessary to compare design levels of engineered structures in the earthquake region with the idealised characteristics of ERD-i types expressed in terms of design intensity or other zone related design coefficients. It is to be expected that in the great majority of cases the actual level of ERD will be the same as the code-consistent level; exceptions will be special structures (where the level may be higher) and cases where the code has not been properly implemented (where the level may be lower).

The range of probable vulnerability classes in the Vulnerability Table is more or less an indicator of the level of ERD provided. Vulnerability classes higher than C or D are in practice restricted to engineered structures with a certain level of earthquake-resistant design (or some wooden structures).

On this basis the actual level of ERD within the expected range of scaling conditions can be stated as follows:

- for RC frame buildings of type ERD-L vulnerability classes C to D are probable, with C being more likely;
- for RC frame buildings of type ERD-M vulnerability classes D to E are probable, with D being more likely;
- for RC frame buildings of type ERD-H vulnerability classes E to F are probable, with E being more likely;
- for RC wall structures of type ERD-L and steel frames (moment-resisting) vulnerability class D is probable;
- for RC wall structures and steel frames (moment-resisting) of type ERD-M vulnerability classes D to E are probable, with D being more likely for RC wall structures and E being more likely for steel frames (moment-resisting);
- for RC wall structures and steel frames (moment-resisting) of type ERD-H vulnerability class E to F is probable, with E being more likely for RC wall structures and F being more likely for steel frames (moment-resisting).

For RC frame buildings without earthquake resistant design vulnerability classes B to C are probable, with C being most likely. For RC frame buildings with serious defects (such as soft storeys, weak columns, lack of stiffening elements like brick infill or shear walls) vulnerability class B or even A may be appropriate. For regular RC frame buildings without ERD but incorporating a certain level of lateral resistance (due to wind load design or stability verifications) vulnerability class D might be representative of exceptional cases.

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 can be regarded as the exceptional case. One should notice that defects will not lead to a such drastic decrease of vulnerability which can be observed in case of RC frame structures.

2.4 Assigning the vulnerability class

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. The decision of which class should be assigned depends on relating the features described above to the symbols shown for the range of possible classes on the Vulnerability Table.

The circle sign shows the most 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.

Some examples may illustrate this process.

(i) A building is unreinforced brick with RC floors, with a weak ground floor (soft storey), and average regularity and construction. The normal class would be C, but the building has no advantages to offset the significant weakness of the soft storey, and can be classed as B, which is within the probable range of vulnerabilities for this building type.

(ii) A building of similar design is unreinforced brick only. This building type is normally class B. The weakness of the soft storey is not enough to downgrade it to class A, as this is in the extreme part of the range. If the building was also in poor condition from having been empty and not maintained for a few years, and internally very irregular in addition to the weak ground floor, this combination of disadvantages would be sufficient to make it class A.

It can often be the case that the weakest buildings in any group are the ones that are damaged first in an earthquake. However, this is not a good excuse to downgrade all buildings one vulnerability class as an automatic procedure. In cases where one has only information on building type (as for example with most historical accounts, when sometimes even this information is lacking) one should normally assign the most probable vulnerability class, and only employ a different class as a means of resolving what would otherwise be an anomalous situation.

2.5 Remarks on introducing new building types

In using the scale outside Europe, or in areas within Europe where a distinctive local building type is found, it may be necessary to deal with building types not covered by the Vulnerability Table as it stands. The following brief guidelines give some indications to how one may proceed. This is unlikely to be a straightforward procedure and is best undertaken by a panel of experts in some controlled way.

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 strong, but not stronger, than normal brick construction, for example, then one may classify the type as being basically of class B. If the type is such that, owing to innate ductility it never performs worse than brick buildings, but in some cases where construction is very good it performs significantly better, then one might deduce that the building type should be represented on the Vulnerability Table as a circle under B and a line extending to C but not to A.

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

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

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

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 Assessing intensity from historical records

3.1 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 (before 1900). It must be stressed, however, that important macroseismic data of the same kind are still available, and used, for earthquakes of the present 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 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, as a large amount of recent literature shows. In particular, the investigator who processes documentary records must be aware that the information has often arrived with him after a long and complicated itinerary. It is of great importance, therefore, to 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, and should not be ignored. 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 spatio-temporal location of the information. This is very important: 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.

These short paragraphs are not intended as a comprehensive guide to practices of historical earthquake investigation, a subject discussed at length elsewhere in the literature.

3.2 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 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 3.5, 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). Very little is known from the general literature about building types in Europe up to the 17th century, except for the obvious facts 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, certainly, most houses in many parts of Europe were made of wood, and the transition to brick or stone was long, and sometimes only partial. Without detailed information, it is very difficult to make any reliable pronouncement on the strength of these structures; it is not certain, for instance, if medieval timber structures were as strong as those known today.

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 than in wealthier towns, 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.

3.3 Total numbers of buildings

In order 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 also. 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 taken into account when assessing intensity, often leading to uncertain - but still useful - 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, etc.

3.4 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 to a number of 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 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 is 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 be contradictory 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 good procedure is to keep a record of how decisions have been reached.

3.5 *Damage to monumental buildings*

Damage to monumental buildings is usually better represented in documentary sources than damage to ordinary houses, for two good 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 as a result of such effects.

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.

4 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 EM-98 scale, and not as a complete handbook on macroseismology. However, there are some points that can usefully be made in the present context.

4.1 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 seen in catalogues where compilers have extrapolated from observed values to calculate a presumed intensity exactly at the epicentre of the earthquake.

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.

4.2 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. While 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 typically show very large scattering, so large as to make the predicted values of limited meaning (although the scattering may be reduced by using spectral accelerations).

For this reason, 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.

4.3 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 is 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.

In most cases there should be no difficulty in converting between MSK values and EMS values on the system MSK = EMS. 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 EMS and 6 EMS. 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 actually 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 EMS.

4.4 Quality of intensity assessment and data samples

A point which is important but 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. 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, his data are a sample from a complete population of observed effects. It is thus valid to ask: Is this sample actually 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. Unfortunately, this is usually not the case. It is recommended that those who are involved with gathering and studying macroseismic information should 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 his data, but he 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 his 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. A useful 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.

4.5 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 uses forms such as "6.5" or "6½" or "6+". It is doubtful if any greater resolution of intensity is either necessary or realisable in practice. If it is felt to be essential for some reason to present more detail, then it should be shown in a descriptive manner.

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, 15 of them suffer damage of grade 1, 10 suffer damage of grade 2, and 5 are undamaged. Of the B class houses, 10 suffer damage of grade 1, 5 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 B2, no A3). 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; it would be possible to 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 definitely 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 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, while 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 so devoid of detail, or so 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 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 suggests 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.

4.6 Damage curves

Early intensity scales generally dealt with damage in a limited and restricted way by stating that, at a certain intensity, a certain type of damage to buildings would occur, the implication being that the damage distribution was uniform. This was mitigated only somewhat by the comment prefacing Richter's 1956 formulation of the Modified Mercalli 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 advance, therefore, when the MSK scale introduced both a qualitative and quantitative approach to damage, and this is followed and developed in the EM-98 scale. The qualitative aspect deals with the type of building and its vulnerability; the quantitative aspect deals with the probability of different grades of damage occurring.

Generally, for those intensity degrees at which damage occurs, a linear progression of damage is observed. 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 encountered in the field, will correspond to those given here.

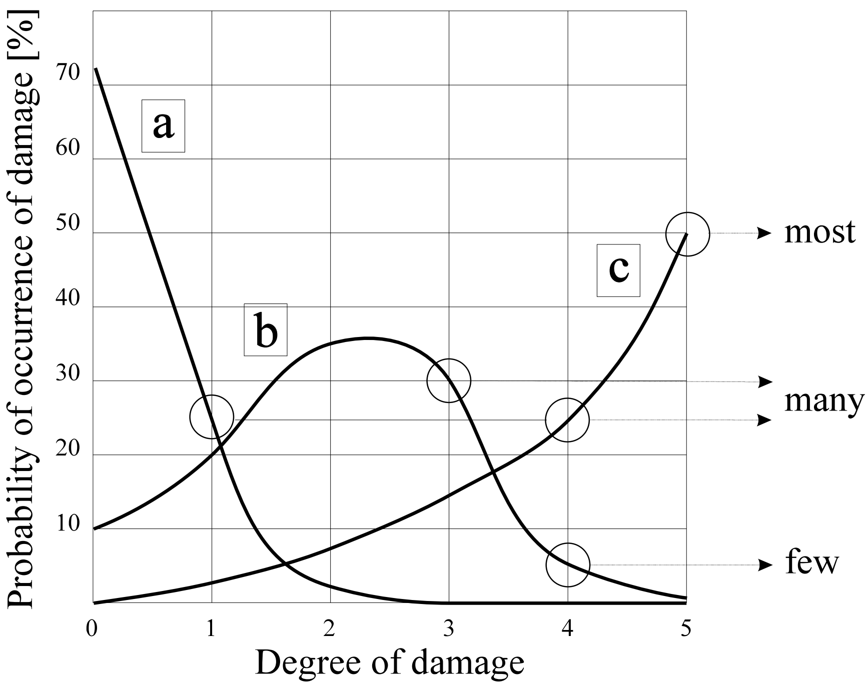
In an idealised case, one could consider the distribution of damage to buildings of equal vulnerability subjected to the same intensity as a normal distribution about the mean damage grade. The damage grades given in the EM-98 scale represent a discretisation of a continuum of possible degrees of damage; such a discretisation has to be made in the interest of easy discrimination in the field. If a more continuous damage function could be plotted, it should show a normal distribution, and 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 in a hypothetical, more continuous function of shaking. One can therefore imagine, again in an idealised case, that as intensity increases, the damage distribution is translated to higher and higher points on the damage function, while retaining its essential shape.

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

This is illustrated diagrammatically in Figure 4-1, in which the three principle damage functions are shown: "type a" for lower intensities (typical for intensity 6), where the function shows monotonically decreasing probability of damage at higher grades; "type b" as being the base case where a normal distribution of probabilities is seen about the mean damage grade, and "type c", which is a monotonically increasing probability with increasing grade of damage, typical of the higher intensities (such as intensity 10). In Figure 4-1 the actual curves shown are typical of field observations from individual building types rather than vulnerability classes, but the principle is the same.

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 Figure 4-1. 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.



◯ intersecting points between typical damage probability functions and damage grades taken for the classification of intensity degrees

Level of intensity:

a I = VI b I = VIII c I = X

Figure 4-1 Relation between typical frequency distributions of damage grades for different intensity degrees and definitions used in the presented intensity scale.

The use of statistical results of damage surveys may be the key for introducing new building types as well as for better correlating particular building types with the most likely or probable vulnerability classes.

4.7 Limitations of twelve degree scales

It may be remarked in passing, that although the EM-98 scale and other scales such as MSK, most versions of MM, etc., have twelve degrees, in practice they tend to function as eight degree scales. Intensity 1 means in practice "not felt", and intensity 2 is so weak as to be usually not reported and so rarely used. At the other end of the scale, intensity 12 is defined in a manner such that it describes the maximum conceivable effects which cannot necessarily be observed in an earthquake. Intensities 10 and 11 are hard to distinguish in practice, so intensity 11 is also rarely used. Thus the "working range" of all these scales tends usually to be from intensity 3 to intensity 10.

4.8 The supposed "missing" degree of the MSK scale

One of the problems to be addressed by the Working Group in the revision of the MSK intensity scale was the perceived problem of a missing intensity degree between 6 and 7 MSK. This problem was considered in some detail, and it was eventually concluded that it is an illusion. That this is the case can be demonstrated quite simply. If the MSK scale was non-linear on account of a missing intensity degree between 6 and 7, this would be very apparent from a study of isoseismal maps. All such maps would show a disproportionately large spatial interval between the isoseismals for 6 and 7 MSK compared to 5 and 6 MSK and 7 and 8 MSK. In thirty years of use of the MSK scale, no-one has ever shown such a problem. Therefore the scale must be correctly linear as defined.

Why, then, does this illusion persist? To answer this question it is necessary to look again at the nature of intensity and intensity scales. If one were to consider ground shaking as a physical parameter, or rather, a combination of physical parameters in which acceleration, velocity, displacement and duration are combined, one can imagine that a complete continuum of possible values exists, ranging from no shaking at all to a maximum credible earthquake motion. Since intensity is in some way an analogue of this combined ground shaking measurement, it too has a hypothetical continual range from nothing to the maximum possible effects.

However, intensity cannot be defined as a continuous parameter. In order to be robust, it has to be discretised into integer values. This means assigning a value to the minimum and to the maximum state and taking a number of evenly spaced points between them, for which the strength of effects at those points can be described in a clear way. It is clearly not the case that Nature should follow the descriptions in the intensity scale in a series of steps; it would be absurd to imagine that in actuality the effects near the epicentre should follow exactly the description for (say) intensity 8 for some distance without variation and then drop abruptly to the description for intensity 7, and so on.

The number of divisions, and where they are made, has to satisfy two criteria: one, that they be evenly spaced, and two, that they be distinguishable from one another in practice. Experience over the course of the 20th century seems to show that the optimum number of degrees that can be discriminated in practice, while retaining even spacing, is twelve. Some workers in special circumstances, especially when working with historical data, have found a lesser number of degrees to be optimal, but for most modern studies, twelve degree scales have been found to work well.

However, that is not so say that some intervening divisions might not be distinguishable, particularly in cases where some sort of threshold effect applies, for instance, that some diagnostic appears for the first time as opposed to merely increasing in frequency of observation. This is the case between intensity 6 and 7, in that one can easily define an intermediary degree that is higher than the description for 6 and lower than the description for 7. However, the fact that one can define such an intermediary degree in this part of the scale more easily than in any other part is not helpful. There is no value in having one extra degree that is not linear with the rest of the scale.

For practical purposes, twelve degrees of intensity should be sufficient, and it is recommended that users do not spend time trying to interpolate intermediate degrees, even in such cases where such steps can be discriminated. The simplest and most robust practice is to round down all “fractional” intensities to obtain the correct integral intensity value. Thus, effects that might correspond to an intermediary degree between 6 and 7 should be assigned a value of intensity 6 EMS.

5 Examples illustrating the classification of damage to building types

The examples of earthquake damage to buildings are classified into different types of structures (cf. the Vulnerability Table of the EMS-98) and the grade of damage (from 1 to 5) they suffered (cf. the Classification of Damage of the EMS-98).

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Adobe masonry	**East Kazakhstan 1990 / Saisan**	1	2	3	4	5
				M		

Comment:

The large and extensive cracks in most walls suggest damage of grade 3.

Figure 5 - 1

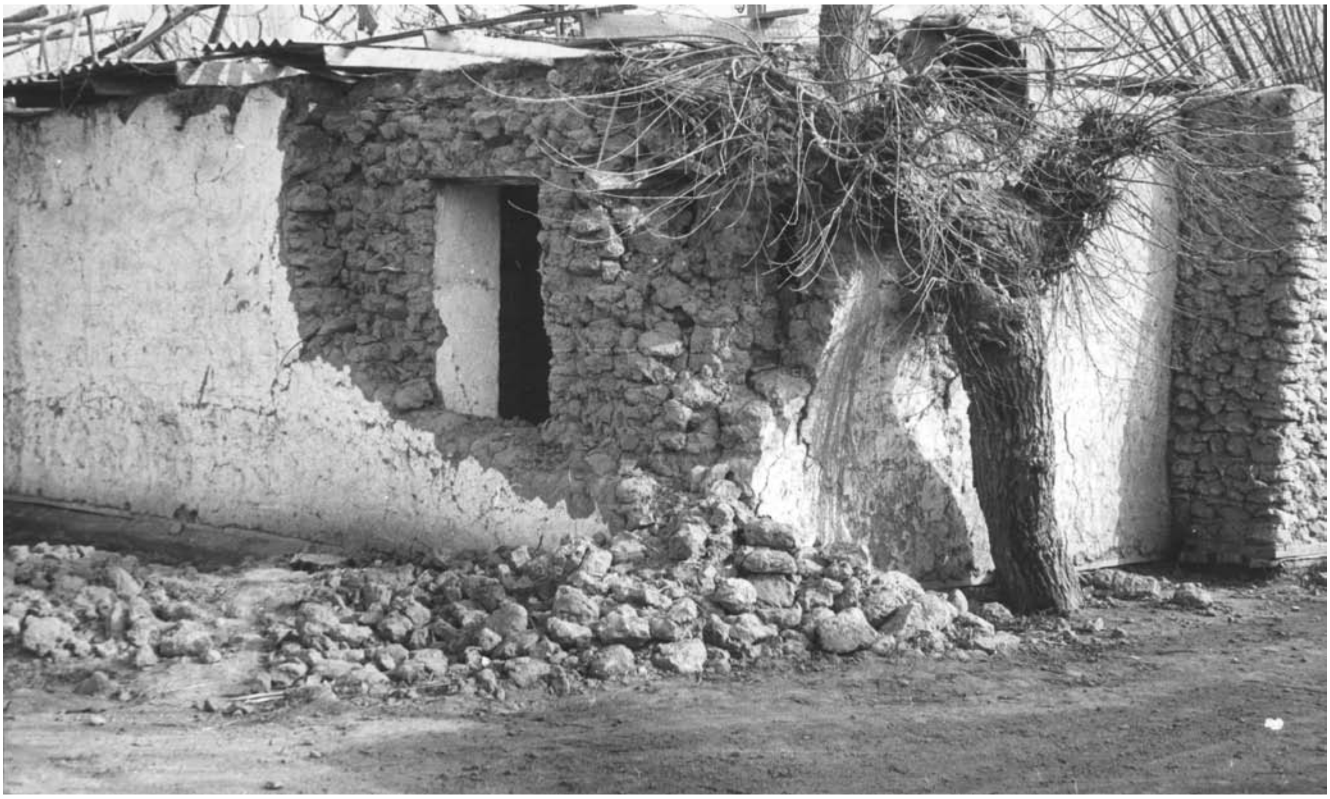
TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Adobe masonry	**Carpathia 1986 / Moldava, Leovo**	1	2	3	4	5
					M	

Comment:

The loss of connection between external walls and the partial failure at the bottom of the left corner suggests damage of grade 4 (serious failure of walls).
The right part of the building seems to be without serious damage and is obviously of a better stage of repair. A final classification should consider the reasons for this difference.

Figure 5 - 2

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Adobe masonry	**Tadjikistan 1985 / Kairakkoum**	1	2	3	4	5
					M	



Comment:

This example shows serious failure of walls, considered to be damage of grade 4.

Figure 5 - 3

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Field stone masonry	**North Peloponissos, Greece 1995 / Aegion**	1	2	3	4	5
					M	

Comment:

The serious failure of walls in this example is indicative of damage grade 4. The vulnerability is affected by the poor quality of mortar and the non-effectiveness of the concrete elements in the construction.

Figure 5 - 4

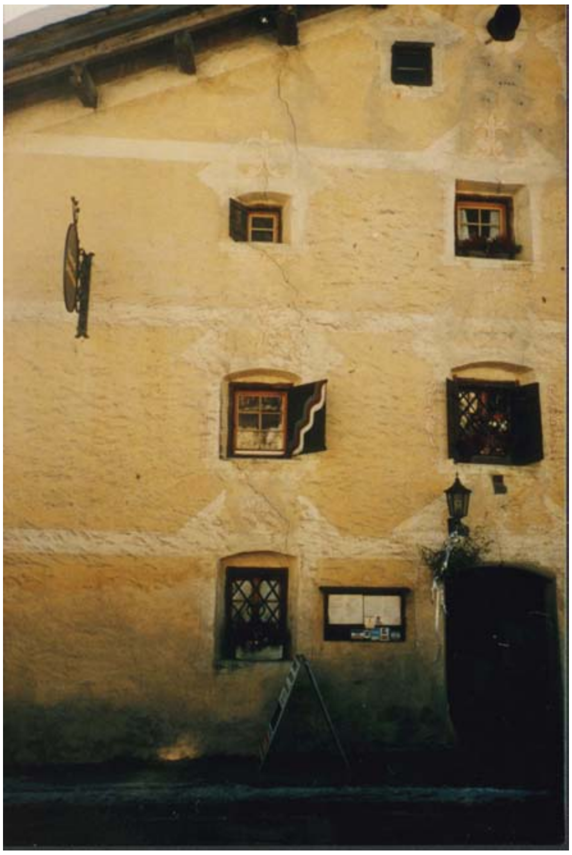
TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Field stone masonry (in very weak mortar)	**Campania-Basilicata, Italy 1980 / Balvano**	1	2	3	4	5
						M

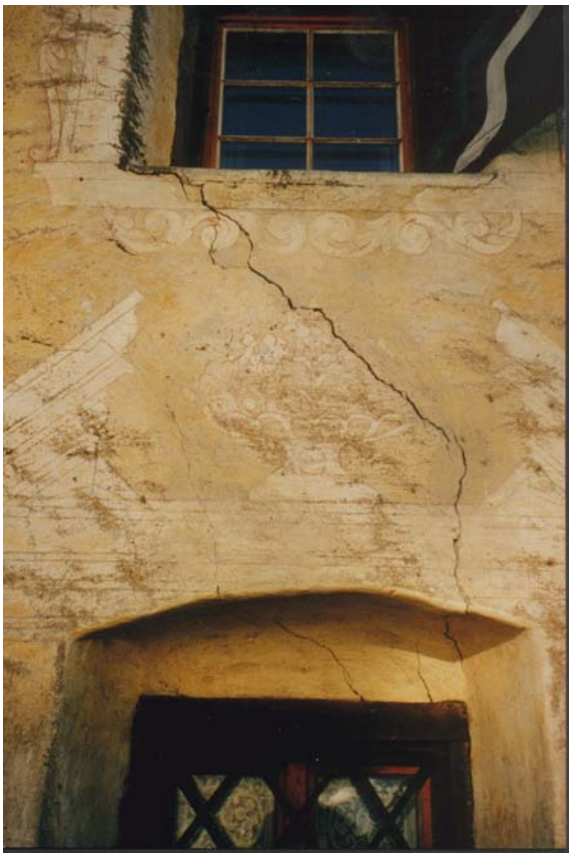
Comment:

The floor slabs have failed and so have most of the walls. This is very heavy structural damage and damage grade 5.

Figure 5 - 5

TYPE OF STRUCTURE	EARTHQUAKE / SITE	GRADE OF DAMAGE				
Simple stone masonry	**Grison, Switzerland 1991 / Vaz**	1	2	3	4	5
			M			





Comment:

The long crack in this wall is large enough to constitute slight structural damage. The damage should be considered to be of grade 2.

Figure 5 - 6

TYPE OF STRUCTURE	EARTHQUAKE / SITE	GRADE OF DAMAGE				
Simple stone masonry	**Montenegro, Yugoslavia 1979**	1	2	3	4	5
				M		

Comment:

The central wall element at the top which failed is a gable wall and not bearing the roof. This is therefore non-structural damage, and should be classified as heavy non-structural damage, which is damage grade 3.

Figure 5 - 7

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Simple stone masonry	**Montenegro, Yugoslavia 1979**	1	2	3	4	5
					M	

Comment:

Parts of the bearing walls have failed, causing partial collapse of the roof and floor slabs. This is heavy structural damage and therefore damage grade 4.

Figure 5 - 8

TYPE OF STRUCTURE	EARTHQUAKE / SITE	GRADE OF DAMAGE				
Unreinforced masonry	**NW-Bohemia - Vogtland 1985, Czech Republic / Skalná**	1	2	3	4	5
			M			

Comment:

Although no structural damage is visible from outside the building, inside it can be seen that cracks have occurred in slot-wall joints, which is slight structural damage. Fairly large pieces of plaster have fallen from the exterior and plaster has also fallen from interior walls. The damage is grade 2.

Figure 5 - 9

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Unreinforced masonry	**Roermond, The Netherlands 1992 / Heinsberg**	1	2	3	4	5
			M			

Comment:

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 chimney on the left of the picture was broken due to the differential shaking behaviour 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.

Figure 5 - 10

TYPE OF STRUCTURE	EARTHQUAKE / SITE	GRADE OF DAMAGE				
Unreinforced masonry	**Swabian Alb 1978, Germany / Albstadt**	1	2	3	4	5
			M			

Comment:

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

Figure 5 - 11

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Unreinforced masonry	**Correggio, Italy 1996 / Bagnolo (Reggio Emilia)**	1	2	3	4	5
			M			

Comment:

Looking at the exterior walls one can see many cracks in the brick infill, indicating damage of grade 2. One should also inspect inside the building in order to confirm this assessment of the damage grade.

Figure 5 - 12

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Unreinforced masonry	**Friuli, Italy 1976 / Gemona (Udine)**	1	2	3	4	5
				M		

Comment:

There are large diagonal cracks in most walls, but they are not so severe and the walls have not failed. In this case the damage is grade 3.
Note: The difference in the classification of damage grade with respect to the subsequent figure.

Figure 5 - 13

TYPE OF STRUCTURE	EARTHQUAKE / SITE	GRADE OF DAMAGE				
Unreinforced masonry, with RC floors	**Friuli, Italy 1976 Braulins (Udine)**	1	2	3	4	5
					M	

Comment:

The large diagonal cracks in the walls, and the partial loss of connection between the exernal walls indicate heavy structural damage. This is damage of grade 4.

Figure 5 - 14

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Unreinforced masonry, with RC floor	**North Peloponnissos, Greece 1995 / Aegion**	1	2	3	4	5
				M		

Comment:

The cracks in the exterior wall are large and extensive, but not all of them penetrate the whole thickness of the wall. This is moderate structural damage and damage of grade 3.

Figure 5 - 15

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
RC frame	**Mexico City 1985**	1	2	3	4	5
				M		

Comment:

This RC building has suffered cracks in columns and infill walls with detachment of pieces of plaster; in some cases there is partial failure of the brick infills. The structural damage (to the columns) is moderate, and the non-structural damage (to the infills) is heavy, making the damage grade 3.

Figure 5 - 16

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
RC frame	**Irpinia-Basilicata, Italy 1987 / Sant' Angelo dei Lombardi**	1	2	3	4	5
					M	

Comment:

Many exterior infill was failed entirely, which is very heavy non-structural damage. In some cases there is heavy damage to the beam-column joints. This is damage of grade 4.

Figure 5 - 17

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
RC frame	**North Peloponnissos, Greece 1995 / Aegion**	1	2	3	4	5
						M

Comment:

The whole ground floor has collapsed completely. In such cases the damage grade is 5.

Figure 5 - 18

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
RC frame	**North Pelopponissos, Greece 1995 / Aegion**	1	2	3	4	5
						M

Comment:

The middle part of this building has collapsed completely, making the damage of grade 5.

Figure 5 - 19

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
RC frame	**Mexico City 1985**	1	2	3	4	5
					M	

Comment:

This building has suffered partial collapse of the upper part. Although single upper storeys have failed, no part of the building has collapsed completely to ground level, so the damage is only grade 4.

Figure 5 - 20

TYPE OF STRUCTURE	EARTHQUAKE / SITE	GRADE OF DAMAGE				
RC frame	**Spitak, Armenia 1988 / Leninakan**	1	2	3	4	5
						M

Comment:

This is obviously very heavy structural damage and near-total collapse, and therefore damage grade 5.

Note: This RC frame structure incorporating a certain level of earthquake resistant design was adversely affected by the insufficient coupling between beams and columns. This building type is a typical example where one should assign a low vulnerability class, in this case B, which represents an exceptionally low class for this type of structure.

Figure 5 - 21

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
RC walls	**Great Hanshin, Japan 1995 / Kobe**	1	2	3	4	5
						M

Comment:

The ground floor has collapsed completely; this is damage of grade 5.

Figure 5 - 22

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
RC walls	**Great Hanshin, Japan 1995 / Kobe**	1	2	3	4	5
				M		

Comment:

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

Figure 5 - 23

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Steel frame	**Great Hanshin, Japan 1995 / Kobe**	1	2	3	4	5
					M	

Comment:

One of the upper storeys of this building has collapsed, and there is lateral flexure of columns; this is heavy structural damage. Some of the heavy curtain walls failed due to the failure of connections. This would be assessed as grade 4 damage.

Figure 5 - 24

TYPE OF STRUCTURE	EARTHQUAKE / SITE	**GRADE OF DAMAGE**				
Timber structure	**Great Hanshin, Japan 1995 / Kobe**	1	2	3	4	5
					M	

Comment:

The building on the left has suffered heavy damage to the joints of the building frame. The damage should be assessed as grade 4.
Note: Due to the weakness of the stiffening system at the ground floor (a soft storey) the whole building has drifted to the right. Lateral support was provided by the building next door, so that in this case the collapse of the building is not total. A good illustration of the effect that can be played by the position of a building relative to other buildings.

Figure 5 - 25

Reference of photographs:

Figures 5 - 1, 5 - 2, 5 - 3 by E.T. Kenjebaev and A.S. Taubaev (Almaty);

Figures 5 - 5, 5 - 7, 5 - 8, 5 - 16, 5 - 17, 5 - 20, 5 - 21 by H. Tiedemann (Swiss Reinsurance Company, Zürich);

Figures 5 - 4, 5 - 6, 5 - 15, 5 - 18, 5 - 19, 5 - 22, 5 - 23, 5 - 24, 5 - 25 by Th. Wenk (Eidgenössische Technische Hochschule, Zürich);

Figures 5 - 13, 5 - 14 by D. Molin (Servizio Sismico Nazionale, Rome);

Figure 5 - 12 by A. Tertulliani (Istituto Nazionale di Geofisica, Rome);

Figures 5 - 9, 5 - 10 by G. Grünthal (GeoForschungsZentrum Potsdam);

Figure 5 - 11 by Landesstelle für Bautechnik Baden Württemberg.

6 Examples of intensity assignment

Example 1 - From documentary data

The following two descriptions are of effects of the 20 July 1564 Alps Maritime earthquake at La Bollène, Roquebillière and Belvédère, in Nissard area (France).

The following account was written by a notary of Nice, Lubonis; the original text was lost and it is known only thank the transcription made by Scaliero, a local historian of XVIII century, who says that this text is annexed to the 1564 notary protocol:

"De admirabili hora et horrendo terremotu in comitatu Niciense facto. Anno ipsi millesimo quingentesimo [quinquagesimo deleted] sexagesimo quarto indictione septima et die iovis vigesima iulii circa unam horam noctis fuit quidam terremotus in Comitatu Niciense absque tamen aliquo damno veruntamen tota nocte per illius discursum sepius iterato ipso terremotu in vale Lantusie qui adeo infremuit et impetum fecit ut locus Bolene omnino devastatus et diruptus remansit ad quod omnes parietes domorum dirupte sunt et duo partes ex tribus personarum eiusdem loci mortui sunt et fere alia tertia pars remansit vulnerata in locis rocabigliera et de bello vedere fere pro dimidia remansit dirupta et devastata adeo quod in loco Rocabigliera mortui sunt viginti due et fere sexaginta vulnerati in loci de bello vedere mortui sunt quinquaginta et totidem vulnerati

a fol. 79 dicto, del prottocolo di Gio. Lubonis del 1564."

The second account is an history of Provence by Caesar Nostradamus, the eldest son of the celebrated Michel; this sources contains a report said to have been left "on a roll written in nissard by someone from the Nice area who passed at Salon [Salon-de-Provence, where Nostradamus spent the last part of his life] in the same time" of the earthquake:

"En ce mesme temps [1564] passa par nostre ville de Sallon, un qui se disoit de ces quartiers là, lequel racomptant ces tristes choses et ces tant estranges prodiges, laissa un roolle en sa langue naturelle et Nissarde qui est comme un vieil Provençal des villes et chasteaux ruynez: ... La Boullene entierement et de fond en comble ruynee, deux cens cinquante morts, et quatorze blessés".

Analysis

This account is typical of the sort of material with which one has to deal as regards early historical earthquakes. The amount of detail is extremely limited, both with respect to the damage and to the type of houses. From a superficial consideration it might seem that the EM scale is less able than other scales to handle cases where detailed information on buildings is not available. This is not the case; other scales either make hidden assumptions about building type which restrict the user's options, or use broad categorisations that provide little resolution.

Taking the case of Bolene, the information reduces to the statement that "all the walls of the houses are collapsed". The questions that have to be asked are: (a) what was the vulnerability class of the buildings; (b) what was the actual grade and distribution of the damage; and, alongside this, (c) to what extent is the report exaggerated? Taking these questions in reverse order: experience shows that some degree of exaggeration is frequently present in historical descriptions of earthquake damage, and the less detail the more likely it is to be inaccurate. Exaggeration comes in two kinds. Quantities can be exaggerated: "all" is more likely to mean "most". Degree can be exaggerated: "collapsed" often turns out to mean "badly damaged". So the probable interpretation of "all the walls of the houses are collapsed" is that most buildings suffered a mixture of damage of grades 4 and 5, some may even have been less damaged. Turning to vulnerability, one might expect a mixture of A and B from what is known generally about historical buildings in the area. If we knew that the exact damage distribution was that many buildings suffered damage of grade 4, then if all the buildings were of class A we would assign intensity 8 and if class B intensity 9. This would give us a range of values over which the intensity might lie in the more likely case of a mixture of A and B classes. Unless one had some reason to suppose that the great majority of buildings should be in one class or the other, an assignment of 8-9 would be the logical outcome. In this case we have the additional uncertainty over the extent of damage, with credible interpretations ranging from many buildings suffering damage of grade 4, a few of grade 5, to most buildings suffering damage of grade 4, many of grade 5. Combining the two uncertainties gives a credible range of intensity values from 8-10. (Note that in the scale, where "many grade 5" is used, " most grade 4" is not always explicitly stated, but it is implied, and can be used.)

For Rocabigliera and de Bello Vedere, "half the houses were heavily damaged". In this case, the interpretation of the damage distribution as "most grade 4, many grade 5" is no longer tenable. "Many grade 4, few grade 5" is still credible, and "many grade 3, few grade 4" can be considered, but fits less well. With the vulnerability again ranging from A to B, this gives an intensity range of 7-9, with 8-9 being more probable

Example 2 - From documentary data

The following two descriptions are of the effects of an earthquake on 7 September 1801 at Comrie, in Scotland. Both are taken from contemporary Edinburgh newspapers. Edinburgh was at that time the nearest place at which newspapers were published. The distance from Comrie to Edinburgh is about 75 km. The time of the earthquake was about 6 a.m.

The following account was written by an observer in Comrie, on 9 September, two days after the earthquake. It was published in the Edinburgh Advertiser (15 September 1801 p.174):
1) "The ... shock ... was very great, and alarming beyond expression. ... Slates fell from some houses, and many loose bodies tumbled down with great precipitation. Sonorous bodies were dashed on each other, and rang loudly, such as bottles, glasses, &c. Several large stones and fragments of rocks fell down the sides of the mountains. Pieces of stone dykes fell, and one bank of earth slid from its place. If the shock had had a little more impetus, it is probable, several frail houses would have been thrown down; but, in the kindness of Providence, no farther harm hath been done than what is above stated."

The second account was also written at Comrie on 9 September, and was published in the Edinburgh Evening Courant (14 September 1801, p.3):
2) ... the noise and shock ... were instantaneous; all those persons who were in bed were terrified that their houses were tumbling down about their ears, and many here and in the neighbourhood jumped out as quickly as possible - its duration might be about five or six seconds, and during all that time the floors, beds, and window shutters shaked violently, and the roofs creaked and strained at a great rate. The horses that were grazing seemed much frightened and to listen with their ears pricked up; the cows also that were housed appeared, from their lowing, to be very uneasy, and all the dogs and other animals gave signs of fear. A shepherd, a few miles to the westward, had just separated a flock of cattle, but as soon as the earth began to tremble they all crowded together in a moment."

Commentary

These two descriptions are quite useful, and contain more information than is often the case for effects in a small village (population in 1801 was about 1500) from a moderate earthquake in this period.

A word needs to be said first about local building type, which would have been predominantly stone-built houses (usually single-storey), with timber roofs covered with slates. These can be considered as vulnerability class B structures. The strength of these buildings is likely to have been quite good, where not affected by disrepair.

A first indication of the intensity degree is usually obtained by looking at the damage. Here the damage is evidently slight, and is not mentioned at all by the second writer. The principal effect observed is the falling of slates from some houses. This is technically grade 3 damage, but since there is no evidence of other types of grade 3 damage (to chimneys or walls) it is likely that those slates that fell were loose. There is no mention of cracks to plaster, but these often go unmentioned (a) because they are not observable from the outside of the building (b) they may not be noticed by the house owner until later, especially if there are other pre-existing cracks. Therefore the absence of mention of damage to plaster is not very significant. The lack of mention of damage to chimneys, which are a prominent feature, is much more significant, especially when the first writer specifically says that no more damage occurred than what he described. The fact that some very weak houses did not fall down is also mentioned specifically.

The first conclusion to be drawn, from a consideration of the damage, is that the intensity is at least 5, but not more than 6. For the intensity to be 7 it would be necessary for there to be more evidence that many houses were damaged, especially their chimneys. This is not the case. The "stone dykes" referred to here are boundary walls. This type of structure is not dealt with by the EM scale as such, but experience shows that this type of damage begins at intensity 5.

Considering effects on people, both accounts agree that the shock was very frightening. People were terrified expressly that their houses were falling. Many jumped out of bed - it is not said that they ran out of doors, but it seems likely, and in this case probably the description fits best with "many people are frightened and run outdoors" for intensity 6. It is clear that the earthquake was felt outdoors (eg. by a shepherd) but not by how many. The effects on people confirm the possible range 5-6, with 6 being more likely.

The first account states that many articles were thrown down violently. This is much more like "small objects of ordinary stability may fall" (intensity 6) than like "small, top-heavy and/or precariously supported objects may be shifted or fall down" (intensity 5), and even resembles "objects fall from shelves in large numbers" (intensity 7).

The clashing of bottles, shaking of window shutters, etc, is an effect which begins at intensity 4 and continues to be observed at higher intensities. Here it is clear that the strength of shaking is at least 5.

The second writer mentions effects on animals. Cows indoors were uneasy (intensity 5) but horses and cattle outdoors were also alarmed (intensity 6).

The cumulative consideration of the above indicates that intensity 6 is the best assessment of the intensity at Comrie for the 7 September 1801 earthquake. Some confirmation can be looked for from seismogeological data. The first writer mentions effects on slopes - large stones and fragments of rock slid down the mountains, and a bank of earth suffered a small slip. The first effect is more like movement of scree slopes than a rockfall, but both effects start at intensity 5 and are typical of 6-7 (6-8 in the case of rockfalls). The second effect is associated with intensities 5-7, but because it appears to be a solitary instance, it is not a very strong indicator. These effects confirm judgements made from an examination of the rest of the data.

Example 3 - From questionnaire data

The following data are extracted from questionnaires relating to the effects of the 26 December 1979 Carlisle earthquake (magnitude 4.8 ML), at Carlisle in Northern England. The questionnaire was published in local newspapers; readers of the newspaper were invited to fill out the questionnaire and send it in. Random sampling techniques were therefore not followed in the collection of data, and percentages calculated from the sample are not guaranteed to be reliable indicators of the total population. The questionnaire was not designed with the EM scale in mind, and therefore not all the questions relate closely to the text of the scale. In this example, therefore, the scale can be shown to work with data which are not optimal.

For the purposes of this study the city of Carlisle was divided into three areas. The data from the western part of the city are used in this example. The number of questionnaires received was 222 from this part of the city. The time of the earthquake was 03h 57m; almost all observers were indoors and in bed. There were no reports from people outdoors, since the streets were deserted at this time of night, on the morning after Christmas Day.

Question: What did you feel?
87% felt some sort of vibration; 19% described it as strong (though they weren't specifically asked to qualify their description); 1% described it as weak; 11% felt no shaking.
Commentary: the vibration was generally observed or strong.

Question: What did others nearby feel or hear?
73% said their neighbours felt or heard the earthquake; 12% said they didn't and the remainder didn't know or didn't answer.
Commentary: the earthquake was felt by most people indoors.

Question: Were you frightened or alarmed?
69% said they were - 18% said they were not. Three people said they ran outdoors, but this information wasn't actually requested by the questionnaire, so more may have done so.
Commentary: many or most people were alarmed or frightened and at least a few tried to run outdoors. So far the intensity looks to be in the range 5-7.

Question: Did doors or windows rattle?
54% said yes; 26% said no.
Question: Did anything else rattle?
54% said yes; 19% said no.
Commentary: the intensity is at least 4 and probably 5 or more from this evidence.

Question: Did any hanging objects swing?
14% said yes; 26% said no, and the rest had no hanging objects to observe, or couldn't see in the dark, or didn't answer.
Commentary: since the shaking from a relatively small earthquake at close range (as here) is likely to be of high frequency, it is not to be expected that there will be many observations of hanging objects swinging. In these circumstances the ratio of approximately 1:2 yes:no replies suggests quite strong shaking, ie at least intensity 5.

Question: Did anything fall over or upset?
18% said yes; 72% said no.
Commentary: The intensity was at least 5.

Question: Was there any damage?
13% reported damage of some sort; 85% reported no damage. Most of the damage was of cracks to plaster and walls; also fall of slates, fall of chimneys and loose bricks dislodged. In one case it was reported that a gap opened between a garage and a house extension.
Commentary: the type of housing is predominantly brick-built. The damage can be summarised as few vulnerability class B buildings suffer damage of grade 1 and 2. This does not match exactly the descriptions given in the scale, but is closer to that for degree 6 than anything else.

Question: Have you any other observations?
A variety of answers were received. Nine people reported that furniture was shifted, an effect first mentioned at degree 6 of the scale.

Summary: The intensity is best assessed as intensity 6 on the evidence above, although the assignment is marginal and some might argue for 5 or 5-6. The degree of damage, the shifting of furniture and the amount of people frightened suggests 6 and the rest of the data are at least consistent with this, though one might expect a higher percentage of observations of items falling.

7 Effects on natural surroundings

The effects of earthquakes on the ground, here summed up by the term "seismogeological" effects, have often been included in intensity scales, including the MSK scale, but are in practice quite hard to use to advantage. This is because these effects are complex, and are often influenced by various factors such as inherent slope stability, level of water table, etc, 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 correlation between these effects and particular intensity grades. Some general considerations on the limited use which may be made of such effects as well water changes, cracks in ground, landslides, or rockfalls are presented separately in this section.

The removal of these diagnostics out of the intensity degree descriptions into a separate section is not taken lightly, particularly as, in rural and sparsely populated (or unpopulated) areas few other data may be available. The problem is, that while variations in the vulnerability of man-made structures can be presented in a reasonably coherent yet robust manner, in the case of effects on nature, most of these depend on complex geomorphological and hydrological features which cannot be easily assessed by the observer (or at all). For example, 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. In a way, the situation is similar to that for the vulnerability of buildings - 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 no way even of estimating the vulnerability in the way that one has for buildings. 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.

It is certainly the case that the extent to which such phenomena occur in a particular earthquake may be observed to vary spatially, and may sometimes be apparently useful for discriminating relative degrees of shaking. For example, one may plot the spatial density of rockfalls or ground cracking. However, recent studies on the spatial distribution of geotechnical parameters such as soil moisture content (of critical importance in determining slope stability) have shown that these properties often show a pattern of fractal clustering. As a result, it has been observed that landslide distributions are typically clustered even when no earthquake has occurred, and what could be mistaken for an intensity-related distribution has nothing to do with earthquake shaking at all.

Therefore, as a general rule, effects on nature should be used with caution and in conjunction with other effects. Data consisting exclusively of effects on nature normally should not be used for assigning intensities. Such data may be used to confirm intensities suggested by other diagnostics. This means that there is always a problem in estimating intensity in an unpopulated area; at best a range of intensities can be given. This is regrettable, but it is better to admit this restriction than to assign intensities which are too unreliable to be useful.

Care must be taken with the location of effects of this kind; they may occur in the countryside some considerable distance from the nearest town, to which they may be attributed by an imprecise report.

For the purposes of the EM-98 scale, seismogeological effects are presented as a Table. For each effect, three types of symbol are used as follows:

lines	- these show the possible range of observation;
circles (empty or filled)	- these show the range of intensities that is typical for this effect;
circles (filled)	- these show the range of intensities for which this effect is most usefully employed as a diagnostic.

These lines are terminated in arrows to show a potential for extreme observations even beyond the limits shown in exceptional cases, different geological settings, or special sensitivity. For some effects, not all three categories are plotted where there is thought to be inadequate experience to formulate an opinion. It should be remembered that for most of these effects, the severity of the observation will increase with higher intensity. Thus for "flow of springs affected", at intensity 5 one might expect slight change in spring flow, while at higher intensities the change may be very much greater. It was decided that attempting to discriminate between "slight change in flow of springs" and "great change in flow of springs" within the scale was not practical owing to the difficulties in quantifying such expressions.

Care must be taken, especially when dealing with ground breaks, to discriminate between geotechnical observations, i.e. those caused by shaking, and neotectonic observations, i.e. those caused directly by fault rupture. This includes major changes in the landscape due to major faulting.

The effects listed in the Table are grouped in four categories: hydrological, slope failure, horizontal ground processes and convergent processes (complex cases). This latter group covers instances where more than one type of process is involved in producing the effect. It should be noted that landslides appear both as slope failure effects and convergent processes effects. This is because some landslides are straightforwardly the result of shaking dislodging rocks, whereas others only occur because slope instability is compounded with certain hydrological conditions. Discriminating between these may not be easy; this is an illustration of the problems that arise in dealing with this sort of effects.

Table 7-1: Relation of seismogeological effects to intensity degrees

Type of effects	Intensities											
	1	2	3	4	5	6	7	8	9	10	11	12
Hydrological effects												
level of well water - minor changes [1]	●	●	○	○	○	○	- -	- -	- -	▶		
level of well water - substantial changes [2]						●	●	●	- -	- -	▶	
long period waves on standing water [3]	—	—	—	—	- -	- -	▶					
waves on standing water from local shaking						●	●	●	- -	▶		
lake water made turbid [4]		◀	—	—	—	—	○	○	○	—	—	—
flow of springs affected [5]				◀	○	●	●	—	—	—	—	—
springs stop and start						◀	●	●	●	—	—	—
water thrown from lakes										◀	—	—
Slope failure effects												
scree slopes move					◀	●	●	—	—	—	—	—
small landslips [6]					●	●	●	—	—	—	—	—
minor rockfalls [7]					◀	●	●	○	—	—	—	—
landslides, massive rockfalls							●	●	●	●	●	●
Processes on flat ground [8]												
minor cracks in ground					◀	●	●	●				
large fissures in ground								●	●	●	●	●
Convergent processes / complex cases												
landslides (hydrological)[9]					●	●	●	●	●	●	●	●
liquefaction [10]							◀	●	●	●	●	●

Legend: ●—● most useful range as intensity diagnostic;
○ intensities also typical for this effect; ——- - - possible observation range;
——▶ potential for extreme observations beyond the given limits

Notes to the table on seismogeological effects

[1]) detected by automatic instruments only
[2]) easily observed changes
[3]) resulting from distant earthquakes; possibly with wave-induced turbidity
[4]) from disturbance of bottom sediments
[5]) rate changes or spring water made turbid
[6]) in loose material in natural (river banks etc.) or man-made (road cuttings) sites
[7]) minor rockfalls in natural (cliffs) or man-made (rock cuttings, quarries) sites
[8]) these two categories blur into one another. The warning is repeated about not confusing ground rupture breaks with fissures caused by shaking.
[9]) landslides with predominant hydrological causes (may be delayed effects)
[10]) liquefaction (e.g. sand craters, mounds formed, etc.)

8 Short form of the EMS-98

The short form of the European Macroseismic Scale, abstracted from the Core Part, is intended to give a very simplified and generalized view of the EM Scale. It can, e.g., be used for educational purposes. *This short form is not suitable for intensity assignments.*

EMS 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, parts of chimneys fall down; older buildings may show large cracks in walls and failure of fill-in 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 good earthquake resistant design are destroyed.
XII	**Completely devastating**	Almost all buildings are destroyed.

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