ANNEX A

Short Form of the EMS-98

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.

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 favorable 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 especially 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.

Section 2 of the European Macroseismic Scale

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 recognized 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 centers. 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 realized 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 recognized 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 summarized 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 chiefly 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/concrete 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 stiffening contribute to a more vulnerable building. One problem to watch out for is the use of systems of cavity walls with internal and external 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 realized 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 characterized 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-columns 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 characterized 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 characterized 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 given 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 depended 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 storey).

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 storey but no walls. Such cases are known as soft storey, 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 neighbor 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 characterized by one ERD-i type only; but for the assignment of intensity it is necessary that information is available which indicate the distribution or individual sites of those buildings. A region or town can be characterized 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-resistant design

This level is characterized 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 its 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 characterized by the realization 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 earth-quake-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 characterized 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 harmonized 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 idealized 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 storey, 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 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.