

Post-earthquake emergency assessment of building damage, safety and usability—Part 1: Technical issues

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Abstract

In this paper, the key technical issues associated with post-earthquake emergency inspections operations of buildings are presented and recommendations are made based on extensive local (Greek) experience from past earthquakes. Safety and usability criteria are established and correlations of such criteria with various damage states are given, along with detailed rules of damage assessment for reinforced concrete and masonry buildings. The damage states of various structural as well as non-structural elements are quantified and their descriptions are supplemented with appropriate photographs of damage in past earthquakes. Rules are then provided for assessing the overall safety of a building based on the severity and extent of damage of its elements. Organisational and logistical aspects of such operations have been presented and discussed in a companion paper (Part 2).

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1. Introduction

The objectives and organisational aspects of building emergency inspection operations, carried out after a damaging earthquake strikes a populated area, have been presented and discussed in a companion paper [1]. Here, more technical issues associated with the assessment of observed damage and its effects on the safety and usability of an inspected building based on previous experience [2–11] are presented. It must be well understood that such inspections are conducted under emergency conditions, primarily to save human life and to protect property from aftershocks. Moreover, it must also be realised that the engineer-inspector will have neither the time nor the usual tools of his trade to come up with a well-substantiated answer to the question of safety. Instead, he must base his assessment on the observed damage, his experience and pertinent training, following certain rules that depend on

the building's structural type. Such rules are given herein for reinforced concrete and masonry buildings and are based on Greek experience accumulated in the last 30 years, as well as on previous work on the subject. An **Earthquake Damage Inspection Form** (EDIF) guiding the engineers to check all the factors affecting building safety has been prepared [2,3] so that reliable assessments with uniformly applied criteria can be reached. The general criteria are followed by detailed rules based on quantitative descriptions of damage in various elements and supplemented with appropriate sketches and photographs.

2. General criteria for safety, damage and usability

In accordance with typical practice in many countries, a building hit by a damaging earthquake is classified in one of three categories based on safety and usability: safe for use, unsafe for use and dangerous for use. The colors **Green**, **Yellow** and **Red** have been used, respectively, for marking the buildings in each of these categories. General safety and usability criteria along with a general description of the associated damage, applicable to any type of

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Posting Classification	Usability	Damage State
SAFE FOR USE (Green) The original seismic capacity of the building has not materially decreased and no major hazard is present. Non observable or slight structural damage. Minor non-structural damage. Use and occupancy allowed, except in areas marked AREA UNSAFE indicating the presence of some local hazard.	Usable with possible restrictions	1-2 = None- Slight
UNSAFE FOR USE (Yellow) The original seismic capacity of the building has been decreased and aftershock hazard may be present. Moderate damage or heavy local damage has occurred. Limited entry is permitted at owner's risk, but not usage on a continuous basis. Entry by public prohibited. Repair and/or strengthening is required. The need for emergency support of the building should be considered.	Unusable-retrofitting required	2-3 = Moderate-Heavy
DANGEROUS FOR USE (Red) Building is unsafe as subject to sudden collapse. Severe structural damage or partial failure has occurred. Entry prohibited (except by authorities) and building surroundings should be protected. This posting does not necessarily imply demolition of the building. Decision on possible repair or demolition should be made after an engineering evaluation of technical possibilities and their economic consequences.	Unusable	3-4 = Severe-Total

Fig. 1. Damage, usability and posting classification of buildings.

building, can be seen in Fig. 1. Depending upon the type of building, the overall damage assessment for such classification takes into account the severity and extent of damage of the various elements, as well as the importance of the damaged elements for the building's integrity and its remaining capacity. For both, severity and extent of damage, a 1–4 numerical scale has been adopted and described as follows:

Damage severity : 1 = None, 2 = Slight,
3 = Moderate to heavy, 4 = Severe to total

Extent of damage : 1 = None, 2 = One to few,
3 = Few to several, 4 = Several to many

As described in the companion paper [1], the inspections operation includes rapid and detailed inspections of all the buildings affected. In the rapid inspection the extent of damage is not recorded, since the inspection is done usually without entering the building, except, perhaps, the ground level. Thus the assessment is based on the externally observed damage. In the detailed inspection both severity and extent of damage are recorded for each type of structural element. In both cases the assessment is made following the general guidelines given herein, taking into consideration how critical the damaged elements are for the safety of the building (e.g. damage in columns versus damage in beams). The guidelines are applicable to reinforced concrete and masonry buildings, the main types found in Greece.

3. Inspection form for damage, safety and usability

A basic tool for conducting good inspections and reaching reliable assessments about a building's safety is the inspection form in which the engineers–inspectors record the damage. The form recommended here is shown as Fig. 2 and has been prepared with the following objectives in mind:

1. To **have one form for both rapid and detailed inspections.** Only the vertical boxes are filled in the rapid inspection, while both vertical and tilted boxes are filled in the detailed inspection.
2. To include only the necessary information about the building, so that it can be filled easily, while at the same time provide the authorities with the needed data.
3. To guide the engineer to check all the necessary information for a reliable assessment. Such information comprises not only the damage in the various types of structural and non-structural elements, but also the type of structural system, existence or not of shear walls, etc.
4. To be self-explanatory and include on its back all the data needed, such as usage categories, structural types and explanations on posting.

There are six groups of information in the EDIF that the inspectors must provide. They are separate sections of the form as follows:

3.1. Section A (Building location and ID)

Most entries in this section are filled during the rapid inspection. In the detailed inspection they are filled only if the information is missing or is incorrect.

- *Section no.* It is provided by the field office. If not available from earlier planning, it must be defined by dividing the affected area into sections.
- *Block no.* It may not exist for a specific area.
- *Streets surrounding block.* Road names are given in sequence.

3.2. Section B (Description of the building)

- Information such as number of apartments, area of story, year of construction, etc., may be found by asking the inhabitants, otherwise should be estimated.
- For type of structural system and for usage, the instructions accompanying the inspection form should be consulted.
- Information on number of basements and on multi-level foundation (detailed inspection) should be filled in only

if available from the building's owners or by inspection if entering the basement poses no hazard.

3.3. Section C (Damage)

- For rapid inspection the “extent” of damage is not entered explicitly. It is estimated only in the detailed inspection.
- The heaviest damage for each element type is recorded.

LOCAL AUTHORITY CrewNo:
 OFFICE..... Report No:
 TEL.....

INSPECTION FORM: RAPID INSPECTION (1st) ☐ DETAILED INSPECTION * (2nd) ☐

**The information in italics need not be filled in during the rapid (1st) inspection*

A. BUILDING LOCATION AND ID
 Street..... No. Postal Code..... Town/Municipality
 Section No: Block No: Or Streets surrounding block: 1..... 2..... 3..... 4..... 5.....
 Position of building in block: ☐ 1=Free 2=Middle (2 opposite sides free) 3=Corner (2 or 3 sides free)

B. DESCRIPTION OF THE BUILDING
 Number of stories ☐☐ Number of apartments ☐☐ Area of story (m2, approx.) ☐☐☐☐ Year of construction* ☐☐☐☐
 Type of structural system: (see back page) ☐☐ Usage: (see back page) GROUND STORY ☐☐
 STORIES ☐☐
 Soft or weak story (e.g. pilotis, etc) YES ☐ NO ☐ Irregularity ☐ 0=None 1= In height 2= In layout 3= Both
 Semi-basement YES ☐ NO ☐ Number of basements ☐ Multi-level foundation YES ☐ NO ☐
 * If built in phases (e.g later additions of stories, strengthening, etc.) use latest year and explain in COMMENTS below.

C. DAMAGE (a) SEVERITY (1st BOX): 1 = None 2 = Slight 3 = Moderate - Heavy 4 = Severe -Total
(b) EXTENT (2nd BOX): 1 = None 2 = 1 to Few 3 = Few to several 4 = Several to many

COLUMNS ☐ ☐ SHEAR WALLS/ ELEV. SHAFT ☐ ☐ FRAME JOINTS ☐ ☐ BEAMS ☐ ☐
 STAIRS ☐ ☐ BEARING WALLS ☐ ☐ INFILL WALLS (masonry, ecc) ☐ ☐
 ROOF ☐ CHIMNEYS, PARAPETS ☐ ☐ BUILDING OUT OF PLUMB ☐ ☐

Apparent ground problems: ☐ 1= None 2= Settlement 3= Liquefaction 4= Slope movement
 5= Ground fissures 6= Rockfalls 7= Other (explain)

Indirect damage: ☐ 1= None 2= Pounding to adjacent building 3= Fire 4= Other (explain).....

Inspected: Exterior ☐ Ground story ☐ 1st story ☐ Other stories ☐

D. OVERALL ASSESSMENT FOR USE (See back page for explanations):
 Safe for use (GREEN) ☐ Unsafe for use (YELLOW) ☐ Dangerous for use (RED) ☐
 The assessment made is : for the whole building: ☐ for part of the building: ☐

E. HUMAN LOSSES (if known): Number of deaths ☐☐☐ Number of injuries ☐☐☐

F. ACTION TO TAKE: ☐ 1 = None 2 = Remove local hazards* 3 = Urgent support required
 4 = Combination of actions 2 and 3 5 = Urgent re-inspection required. 6 = Urgent demolition required

Urgency: ☐ 1 = Low 2 = Medium 3 = High
 * The following elements should be demolished or removed
 Access to the following areas is prohibited and must be blocked.....
 The following utilities must be disconnected: electricity ☐ water ☐ gas ☐

COMMENTS:

INSPECTION TEAM DATA
 1. Signature..... 2. Signature
 Name/ Title..... Name/ Title.....

INSPECTION FORM RECEIVED BY: Owner ☐ Building manager ☐ Other ☐
 Recipient's Signature Name Date

(a)

Fig. 2. (a) Front page and (b) back page of the Earthquake Damage Inspection Form (EDIF).

Data for filling the form

USAGE		
10 = Residential	11 = Open (pilotis)	
20 = Office		
30 = Commercial shop		
40 = Hospital/clinic	41 = Social welfare (retirement home, daycare center, etc.)	
50 = Administrative	(central or local government) except critical services	
	51 = Police	52 = Fire station
	54 = Energy production or distribution	53 = Communications
60 = Public Assembly	61 = Schools	55 = Water distribution-management
	62 = Historical and religion	63 = Sports
	64 = Culture / Entertainment (museum, theatre, etc)	
70 = Hotel	71 = Restaurant, Café, Bar, etc	
80 = Industrial	81 = Small production units	
90 = Parking	91 = Other (specify)	

TYPE OF STRUCTURAL SYSTEM		
10 = Masonry	11 = Wooden floors and roof, no belts	
	12 = Wooden floors and roof, with horizontal belts	
	13 = Concrete floors and roof, no belts	
	14 = Concrete floors and roof, with additional belts	
	15 = Concrete floors, no belts	
	16 = Concrete floors, with additional belts	
20 = Reinforced Concrete cast in place	21 = Frame type with infill walls (brick, etc)	
	22 = Frames and shear walls with infill walls (brick,etc)	
	23 = Frame type with lightweight partitions	
	24 = Frames and shear walls with lightweight partitions	
	25 = Frames with infill walls and lightweight partitions	
	26 = Frames and shear walls with infill walls and lightweight partitions	
30 = Prefabricated concrete	31 = Frame type	32 = With panels
40 = Steel frames		
50 = Mixed	51 = Composite (Concrete and steel)	52 = Masonry and concrete
60 = Wood frames		

EXPLANATIONS FOR POSTING (Correlation with damage in Tables A1 to A4 of the Field Manual)

Safe for use (GREEN)	The building is generally safe and may be used subject to any posted restrictions.
Unsafe for use (YELLOW)	The building has suffered damage as indicated and must not be used before a detailed (2 nd) inspection is performed. Entry permitted at own risk and only for a limited period of time. Aftershocks may cause injury or even death. Safety measures stated herein must be taken immediately.
Dangerous for use (RED)	Danger of partial or total collapse of the building and serious danger of injury or death. Entry is prohibited. Safety measures stated herein must be taken immediately. Detailed inspection will follow. This posting does not necessarily imply demolition of the building.

COMMENTS:

.....

.....

(b)

Fig. 2. (Continued)

- No damage is indicated using numeral 1. A non-existing element is indicated by zero value (0).
- The assessment of damage is made on the basis of Tables 1 and 2, the pertinent photos (Figs. 3–5) and by exercising engineering judgment. This applies to both severity and extent.

3.4. Section D (Overall assessment for use)

The overall assessment for use should be made by taking into account Tables 3 and 4, which combine the (highest observed) severity of element damage with an estimate of its extent (number of elements having suffered the

particular level of damage) as recorded in Section C of the form. Pertinent photos (Figs. 3–5) should also be consulted. The final assessment should be based on sound engineering judgment, keeping in mind that safety of the occupants, not repair costs, is the basic criterion and that the given correlations between damage assessment and posting color on the basis of severity and extent is indicative and should not be followed blindly. If the building is generally safe except that some local hazard is present (Section F marked), the building is posted as Green (safe) with restrictions. It is posted Yellow or Red if ground problems are present and their severity cannot be assessed. In case of doubts, the inspectors are instructed to be conservative, but not on a systematic basis. Note that a

Table 1
Typical damage severity for reinforced concrete buildings

Damage severity	Damage description
1 = None	1. No signs of any distress 2. Very light non-structural damage 3. Fine cracks in few infill walls and in mortar. Light spalling of concrete
2 = Slight	1. Small cracks ($d \leq 3.0$ mm) in a few infill or partition walls 2. Cracks and/or spalling of concrete in some structural elements. Indicative crack widths are: Beams: $d_{\text{diag}} \leq \sim 0.5$ mm, $d_{\text{vert}} \leq \sim 2.0$ mm Columns: $d_{\text{diag}} \leq \sim 0.5$ mm, $d_{\text{horiz}} \leq \sim 2.0$ mm Shear walls: $d_{\text{diag}} \leq \sim 0.5$ mm, $d_{\text{horiz}} \leq \sim 1.0$ mm Stairs: $d \leq \sim 3.0$ mm Slabs: $d \leq \sim 1.0$ mm 3. Disturbance, partial sliding or falling down of roof tiles. 4. Cracking or partial failure of chimneys and parapets 5. Inclination of building barely visible
3 = Moderate–Heavy	1. Extended large diagonal or other cracking in partition or infill walls ($d > 3.0$ mm) in one or more stories. Detachment or partial failure of walls. 2. Spalling-partial disintegration of concrete. Larger cracks in several structural elements. Indicative crack widths are: Beams: $d_{\text{diag}} \leq 2.0$ mm, $d_{\text{vert}} \leq 4.0$ mm Columns: $d_{\text{diag}} \leq 2.0$ mm, $d_{\text{horiz}} \leq 5.0$ mm Shear walls: $d_{\text{diag}} \leq 1.0$ mm, $d_{\text{horiz}} \leq 3.0$ mm Stairs: $d \leq \sim 10.0$ mm Slabs: $d \leq \sim 2.0$ mm Joints: $d \leq \sim 2.0$ mm 3. Dislocation and/or partial collapse of chimneys and parapets. Sliding and/or failure of roof tiles 4. Visible inclination of building. Slight dislocation of structural elements 5. Minor ground movement but no signs of foundation failure
4 = Severe–Total	1. Partial or total collapse 2. Widespread failure of infill walls or severe cracking visible from both sides in one or more stories. 3. Large number of crushed structural elements and connections, exposure and buckling of reinforcement in several locations, disintegration of concrete, Indicative crack widths are: Beams: $d_{\text{diag}} > 2.0$ mm, $d_{\text{vert}} > 4.0$ mm Columns: $d_{\text{diag}} > 2.0$ mm, $d_{\text{horiz}} > 5.0$ mm Shear walls: $d_{\text{diag}} > 1.0$ mm, $d_{\text{horiz}} > 3.0$ mm Stairs: $d > \sim 10.0$ mm Joints: $d_{\text{diag}} > 2.0$ mm 4. Collapse of chimneys and parapets. Extensive damage and/or sliding of roof 5. Considerable dislocation of structural elements, residual drift in any story or dislocation of the whole building 6. Substantial ground movement, uplift of footings or fracture of foundation

Notation: d_{diag} —width of diagonal cracks (inclined to the axis of the element). d_{vert} , d_{horiz} —width of vertical and horizontal cracks (to the element axis), respectively.

detailed inspection may change the posting made by a rapid evaluation.

3.5. Section E (Human losses)

Information is typically obtained from the residents.

3.6. Section F (Action to take)

Any urgently required measures along with the degree of urgency are specified here, unless such measures have already been taken (due to a previous rapid inspection). These could be urgent demolition of the whole building, removal of local hazard (e.g. removal of a hazardous chimney, parapet wall), urgent support, etc. In addition, if utilities must be disconnected the inspectors should see to it

and if unsuccessful they should indicate so on the form. Also, hazardous areas around the building must be properly barricaded.

3.7. Comments

Any comments deemed necessary either to explain the posting, the assessment of damage, or the information given in the form should be provided.

4. Inspection form for damage, safety and usability assessment

In what follows, criteria are given for assessing the severity of damage in relation to various types of failure for reinforced concrete and masonry buildings [2,3]. It is noted

Table 2
Typical damage severity for masonry buildings

Damage severity	Damage description
1 = None	1. No signs of any distress 2. Hairline cracks in partition walls visible from one side only
2 = Slight	1. Small cracks in partition walls visible from both sides (width $d \leq 3.0$ mm) 2. Small cracks in bearing walls, starting mostly at the corners of a few openings ($d \leq 3$ mm). 3. Patches of mortar falling from ceilings or walls 4. Disturbance, partial sliding and falling down of some roof tiles
3 = Moderate–Heavy	1. Substantial cracking of partition walls ($d > 3.0$ mm) 2. Diagonal cracking in bearing walls ($d < 5.0$ mm), but not so extensive as to constitute failure 3. Movement, separation or local failure of roof and floor framing supports 4. Dislocation and/or partial collapse of chimneys, parapets or roofs 5. Local heavy damage in some part of the building
4 = Severe–Total	1. Bearing walls with large cracks ($d > 5.0$ mm), visible from both sides 2. Partial or total failure of bearing walls, floors and/or roof 3. Walls out of plumb 4. Failure of floor and roof support areas and dislocation of their framing 5. Any type of damage indicating considerable danger for collapse

Notation: d —width of cracks.

here that the various damage descriptions listed in the tables are indicative of the corresponding level and that the presence or absence of one type of damage given in a list does not necessarily imply classification or no classification in the respective category. Engineering judgment will always be required and the guidelines listed herein must be used as an aid rather than a substitute for such judgment.

Damage severity of the various structural and non-structural elements for different types of buildings, reinforced concrete or masonry, is decided with the aid of the guidelines given in Tables 1 and 2, respectively.

Extent of damage refers to the number of elements with the particular damage severity marked. In case different degrees of damage for the same type of element exist, (e.g. damaged columns with level of severity 2–4) the heaviest level of damage severity is indicated and for this level of damage the respective extent of damage is recorded.

On the basis of element damage, the overall assessment for use, accounting for damage severity and extent, is subsequently made by following again appropriate guidelines (Tables 3 and 4).

It is of paramount importance that the inspector identifies first the type of structural system (section B) from which the “criticality” of each load-carrying element can be assessed. Subsequently the damage must be recorded, as Section C of the EDIF requires. It is only then that the assessment of the building’s safety can be made with sufficient degree of confidence. Although it is quite difficult to automate such assessment just on the basis of observed (and recorded) damage, an effort has been made aimed at an as much as possible objective assessment, on the basis of the outlined general safety and usability criteria. It is based on the recorded damage for load

bearing and other elements (reinforced concrete members, bearing walls, infill walls, chimney, parapets, roofs) and on the contribution of such elements to the building’s seismic capacity and the hazard they pose.

In summary the steps for safety assessment of the building are:

1. Damage severity (1–4) and extent (1–4) of the damaged structural elements are recorded in Section C of the inspection form (Tables 1, 2, Figs. 3–5).
2. An assessment of damage for the individual elements is made, based upon the criteria given in Table 3, which relate the damage severity (and extent) to the elements’ damage. To this purpose the following letter symbolisms for the individual groups of elements are adopted.
 - A: RC columns, beams, shear walls, frame joints and masonry walls; B1: Stairs; B2: Infill walls; B3: Parapets, roofs, chimneys; C: Building out of plumb; D: Ground problems.
3. An “Overall Assessment for Use” of the building (Green, Yellow or Red; Section D of the inspection form) is made as shown in Table 4 taking into account the partial “overall damage assessment classifications for the individual elements”.

As it may be observed, of crucial importance to the overall assessment of the building are the damages to bearing elements (group A), stairs (B1), infill walls (B2), building out of plumb (C) and ground problems (D). The overall assessment for use of the building as a rule follows the partial damage assessment of any of these categories. Damage in secondary elements i.e. parapets, roofs and chimneys (B3) does not influence an otherwise undamaged

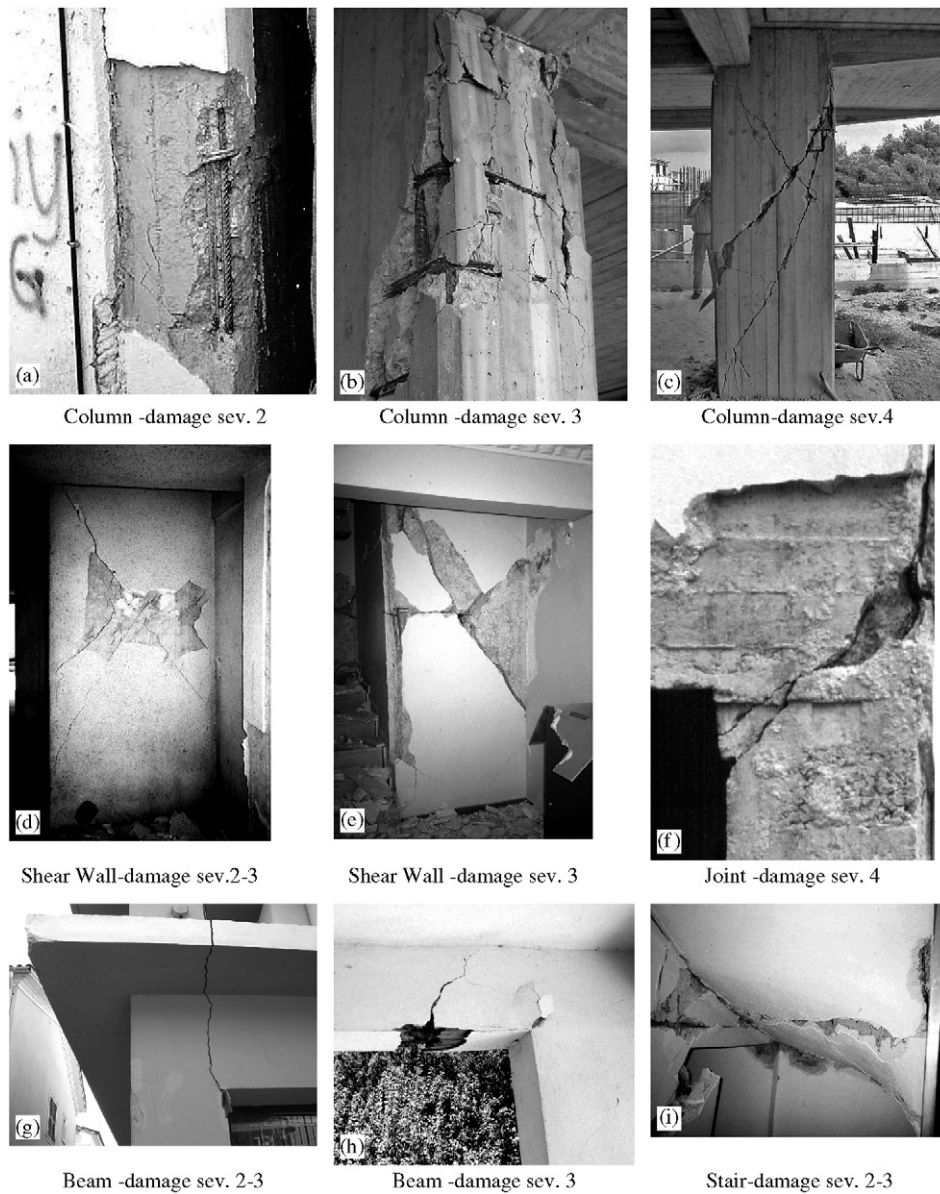


Fig. 3. Damage severity for various R-C structural elements.

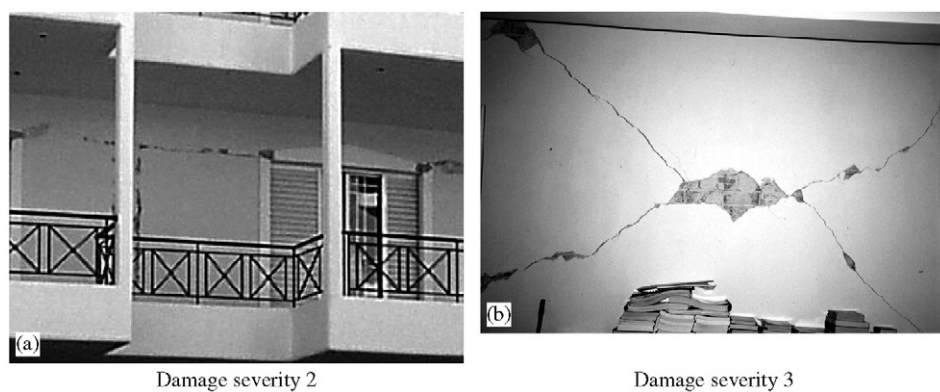


Fig. 4. Damage severity for infill walls.

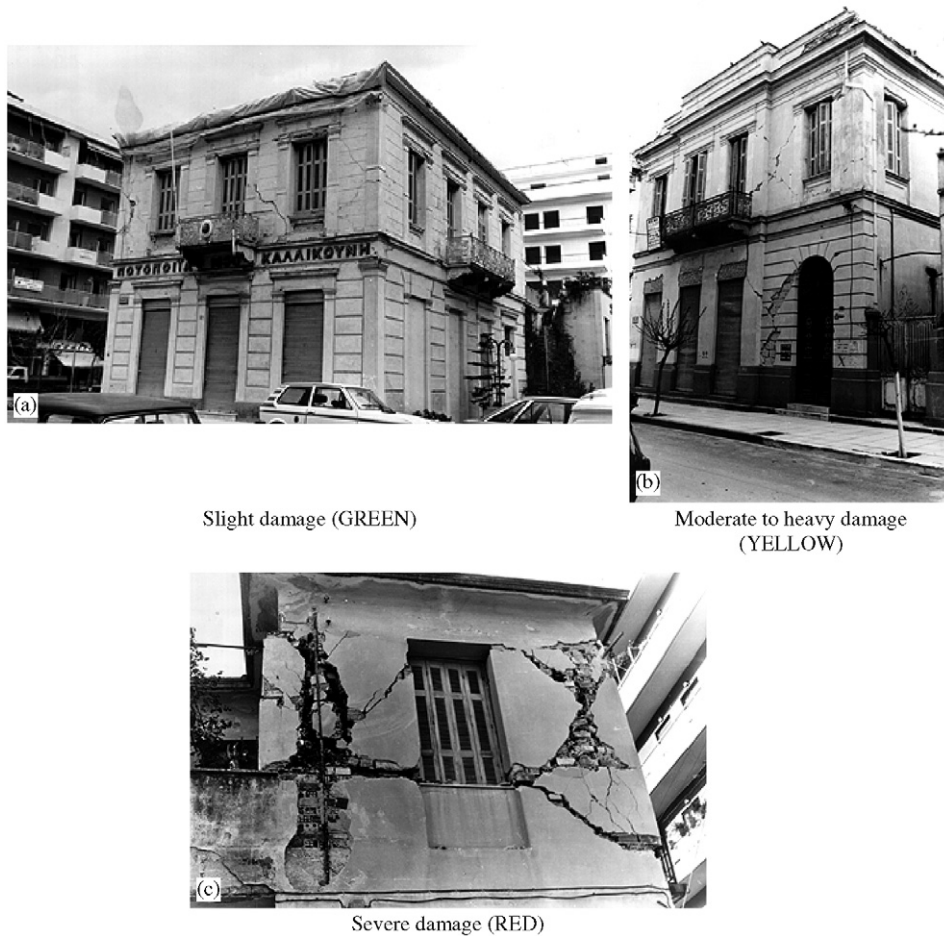


Fig. 5. Various damage degrees for masonry buildings.

building; the building is marked Green with possible restrictions and/or need for interventions.

It is once more emphasised, however, that the rules given herein should always be viewed as an aid rather than a substitute to engineering judgment.

5. Reinforced concrete buildings

Reinforced concrete buildings constitute the dominant type of construction in the earthquake prone countries of Europe. They can be found as single story houses, multi-story residential or office buildings, industrial complexes, etc. Concrete construction can be cast in place or pre-cast or a combination of both.

Cast in place concrete buildings constructed before modern codes were introduced (in Greece before 1980) can be quite vulnerable to strong earthquakes, especially if they were built under poor quality control. The majority of multi-story buildings that have collapsed in catastrophic earthquakes of the recent past belong to this category and are responsible for most of the recorded human losses. Their design, not based on the modern concepts of ductile behaviour, good confinement, strong columns-weak

beams, strong shear walls with specially detailed boundary elements, etc., makes them quite more vulnerable than the new buildings designed on the basis of modern codes. Older structures are likely to have poor detailing so that an earthquake with several cycles of strong shaking could cause damage to the load-carrying vertical members, and consequently, lead to rapid strength deterioration.

In many of the concrete buildings the partition walls are brick infills that are normally not accounted for in design (according to normal practice so far). Experience from damaging earthquakes in Greece has shown that such infills had a very beneficial effect that may have saved several poor quality buildings from collapse. Being quite stiff, brick infills attract most of the earthquake-induced forces in the first few cycles of shaking, suffering extensive cracking as a result. This cracking contributes to an increase in damping and hence to a reduction in the forces transmitted to the concrete members. Thus, the infills act as a first line of defence against the earthquake, offering substantial protection to the load carrying concrete structure. Heavily damaged infill walls, however, can be quite hazardous posing a threat to people. Thus, given that safety of the occupants is the main objective of the

Table 3
Criteria for assessment of element damage (for notation see text)

Type of damage	Assessment	Damage severity	Damage extent
A. Bearing elements columns, beams, shear walls, frame joints, masonry walls	Green	1, 2	1, 2
	Yellow	2	3, 4
		3	2
	Red	3	3, 4
		4	2, 3, 4
B1. Stairs	Green	1, 2	1, 2
	Yellow	2	3, 4
		3	2
	Red	3	3, 4
		4	2, 3, 4
B2. Infill masonry walls	Green	1, 2	1, 2, 3, 4
		3	2
	Yellow	3	3, 4
		4	2
	Red	4	3, 4
B3. Parapets, roofs, chimneys	Green	1, 2	1, 2
	Yellow	2	3, 4
		3	2
	Red	4	2, 3, 4
C. Building out of plumb	Green	1, 2	
	Yellow	3	
	Red	4	
D. Ground problems	Green	1	
	Yellow or	2, 3, 4, 5,	
	Red	6	

Table 4
Criteria for overall assessment for different types of damaged elements according to Table 3 (for notation see text)

No.	Damage assessment of the various element categories (A–D)	Overall assessment of the building
1	A, or B1, or B2: Red	Red
2	A, or B1, or B2: Yellow and B3: Green	Yellow
3	A and B: Green and C or D: Yellow or Red	Yellow or Red
4	A and B: Yellow and C or D: Yellow or Red	Red
5	A and B1 and B2: Green and B3: Yellow or Red (and C or D: Green)	Green
6	A and B1 and B2 and B3: Green	For part of the building Need for intervention in ... Green

emergency inspection, the damage to infills should be assessed accordingly (as suggested in Table 1). For instance, no visible damage in the main structural elements but heavily cracked infills is a case that would normally be posted Yellow or Red since the seismic capacity of the building is obviously reduced.

Prefabricated concrete buildings are damaged typically in their connections, which must be the first areas to be inspected.

In Table 1 the levels of damage severity of RC buildings are related to the observed types of damage in the various elements. Corresponding photos (Figs. 3 and 4) are quite useful, at least for inexperienced inspectors.

6. Masonry buildings

Masonry buildings may have been built from a variety of materials (e.g. stone, hollow or solid bricks, special concrete blocks) and in a variety of ways (e.g. with or without steel reinforcement, with or without horizontal or other belts, etc.).

In Table 2 the levels of damage severity of masonry buildings are related to various types and levels of damage in the walls, roof, floor, etc. Photos in Fig. 5 will assist the inspectors to reach valid assessments.

The guidelines given are general enough to cover all cases, but here again particular attention should be paid, taking into account the great variability in the mechanical properties of the bearing masonry walls.

7. Rules built in the PEADAB program for posting based on the damage assessment

In an effort to set the basis for an expert system that will assist inspectors post the damaged buildings with uniform criteria, a number of rules have been developed [2,3] with which the PEADAB [4] system will check the posting classification of the building for possible inconsistencies with the recorded damage. If the posting given by the inspectors does not agree with the rules, PEADAB will print a warning message and the inspectors will need to review their posting. These rules have been developed only for reinforced concrete and masonry buildings from which practically all of the Greek experience comes, and are summarised in Tables 3 and 4. It is noted that for rapid inspection the system takes into account only the damage severity recorded in the inspection form (vertical squares) while for detailed inspection the system takes into account both the damage severity and the damage extent, also recorded in the inspection form (vertical and tilted squares).

8. Concluding remarks

Assessing the seismic capacity and safety of a building damaged by a strong earthquake is generally a difficult task. It is even more difficult to do it only by visual inspections, carried out in short periods of time, under emergency conditions and under the threat of continuing aftershock activity. In this paper, a quantification of typically observed earthquake damage in reinforced concrete and masonry buildings has been presented, based primarily on Greek experience from a number of catastrophic earthquakes in

the past 30 years. The damage is quantified for the various types of structural or other elements in the building, both in terms of severity and extent. On the basis of such quantification an overall assessment for safety and usability of the building is made. An attempt has also been made to establish well defined rules as seeds of an expert system, which could help in reaching as objective assessments as possible, once the type of structural system and the observed damage have been identified and recorded. Adopting the procedures and assessments presented herein will facilitate the work of the inspection teams, reduce the time required to complete the job, secure that no valuable information is lost and, finally, will lead to more objective and uniform assessments of building safety.

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Photograph Credit

Figs. 3b, 3c, 3h, 4a	by T.B. Allemark
Fig. 3a	by S. Anagnostopoulos
Figs. 3d, 3e, 3i, 4b	by M. Moretti
Fig. 3f	by EPPO
Fig. 3g	by V. Lekidis
Figs. 5a, 5b, 5c	by M. Fardis

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