POST - EARTHQUAKE EMERGENCY ASSESSMENT OF BUILDING SAFETY

FIELD MANUAL

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DISCLAIMER

The information contained in this manual has been compiled with every possible care and reflects current state of knowledge and experience on the pertinent subjects. However, since earthquake engineering is a field with many uncertainties, far from being an exact science, application of the methods, procedures and criteria recommended herein does not guarantee full protection of life and property. It should be applied by competent personnel and only after careful examination of its applicability to the local conditions and structural types.

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Acknowledgements

In February 1994, the European Commission (Directorate General XI, - Civil Protection) awarded the University of Patras a contract to develop guidelines, criteria and procedures for post-earthquake emergency assessment of building safety. A computer system that would support the planning and execution of such operations was also to be developed.

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FIGURE AND PHOTOGRAPH CREDITS

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Fig 5. :	by T. Karantoni

1. PURPOSE AND SCOPE

The purpose of this manual is to serve as a blueprint for setting up and carrying out efficiently an operation of post - earthquake emergency building inspections in populated areas stricken by a damaging earthquake. These inspections will identify which buildings are safe for immediate use or occupancy and also which buildings are unsafe so that people will be kept from using or entering them. If the number of affected buildings is large, the inspections operation can turn out to be a major undertaking, whose success depends upon the way it has been designed and planned in advance. This is especially so, given the chaotic conditions that a catastrophic earthquake creates.

This manual contains guidelines for the engineers carrying out the emergency inspections, including safety classification criteria, descriptions of typical levels of damage for different types of buildings and the relation of such damage to safety. It also includes recommendations about safety precautions that must be taken by personnel in the field. In addition, it provides an operational plan for organising and executing the inspections as well as the necessary subsequent actions. Thus, the manual is also intended for use by preparedness planners and by the officials charged with dealing with the emergency created by the earthquake.

2. THE EMERGENCY INSPECTIONS OPERATION : AN OVERVIEW

The operation of emergency inspections of damaged buildings should start within hours, if possible, after the earthquake strikes.

The main tasks of the operation are:

1. Inspection of all the buildings in the affected area and posting them as to their safety.
2. Identification of hazards associated with damaged buildings and their removal.
3. Identification of those buildings that require emergency support to avoid collapse and execution of the required work.

2.1. Objectives of the operation

A prerequisite for the success of the operation is to have clear and well defined objectives that all the people involved in it will know. In particular, the structural engineers - inspectors, key personnel in this operation, should keep them always in mind in order to optimise their time and efforts. Ranked by their importance, these objectives are:

1. Protect human life
2. Save properties
3. Minimise : (a) the number of homeless and (b) the loss of economic activities, by identifying as soon as possible all buildings that are safe to occupy and use.
4. Indicate unsafe areas around hazardous buildings, identify temporary shelter sites and provide the number of required temporary housing units.
5. Provide the necessary data for obtaining reliable estimates of the disaster that will allow authorities to take relief measures, formulate disaster mitigation policies and allocate available resources.
6. Provide data that will identify frequent causes of damage, so that potential rehabilitation plans may take into account such assessments.
7. Provide data for practical research studies that may lead to revaluation of existing codes and construction practices, to updates of seismic hazard

maps and to elaboration of seismic vulnerability models for pre - earthquake planning purposes.

To be successful in meeting the above objectives, the operation must:

1. Be well organised.
2. Yield uniformly reliable assessments and damage data.
3. Be completed in a short period of time.

2.2 Inspections and posting

The emergency inspections are carried out by teams of two structural engineers, who are assisted, if resources permit, by a driver - technician. These engineers could be public employees or volunteer professionals and should, ideally, have some previous training for this type of work. For an efficient operation, a rapid assessment is first carried out to screen obviously safe and unsafe buildings, followed by a detailed evaluation of those buildings that fall in neither of these two categories. The procedure is shown schematically in Exhibit 2.1. A rapid assessment should not take more than about 30 minutes per building to complete and will result in the posting of every building as SAFE (Green), LIMITED ENTRY (Yellow) or UNSAFE (Red). The posting “LIMITED ENTRY” will be used for all the damaged buildings for which there is uncertainty about the extent to which they have been weakened by the earthquake. Such buildings will be subjected to a second, more detailed inspection that would take anywhere between 1.0 to 3.0 hours to complete. A detailed inspection could result in changing the posting to either green or red, but could also leave the same (yellow). All critical facilities or other important buildings must undergo detailed inspections from the beginning. The inspectors will be filling an appropriate posting placard and a Damage Inspection Form (Exhibits 2.2 - 2.5), in which their recommendation for further action will be marked. For the rapid assessment, only the left side of the form and the posting section on the right need be filled, while for the detailed inspection, both the left and right sides of the form should be completed. The posting placard(s) will be placed at or near all entrances of the building to be clearly visible by anyone who wants to enter. To deter removal of the placard, a permanent spot should also be marked on the building next to the placard, using a spray of the same colour i.e. green, yellow or red. AREA UNSAFE

signs will be placed at the barricaded sections. The inspections will identify potential hazards in the damaged buildings that will require immediate removal and also those buildings that need emergency support to avoid collapse. After damaging aftershocks, reinspection of some of the buildings may be necessary.

2.3. Hazard removal and emergency supports

The emergency inspections provide information about hazardous conditions in buildings requiring quick intervention. Hazard removal will begin as the inspection data start coming in. It could range from the removal of some local hazard e.g. a badly damaged chimney or parapet, to the demolition of complete buildings that have been damaged beyond repair or have partially collapsed (Fig. 1,2).

The necessary work will be carried out by specialised crews and requires availability of the necessary equipment. Similarly, work to provide emergency support for seriously damaged buildings will begin with the arrival of the damage data when the inspections get under way. Emergency bracing and shoring (Fig. 3,4) will be carried out by special crews under the direction of an experienced structural engineer.

The daily program for hazard removal and emergency support will be prepared on the basis of the information brought in by the inspectors, after careful assessment of each case and of the urgency for action it presents. Such assessment will also include any requests for priority intervention, made be owners of damaged buildings.

Fig. 1 Partially collapsed wall and parapet, requiring urgent demolition

Fig.2 Hazardous, partially collapsed masonry building requiring urgent demolition

Fig. 3 Emergency support due to failed column

Fig.4 Emergency support of damaged, open ground story, of concrete building

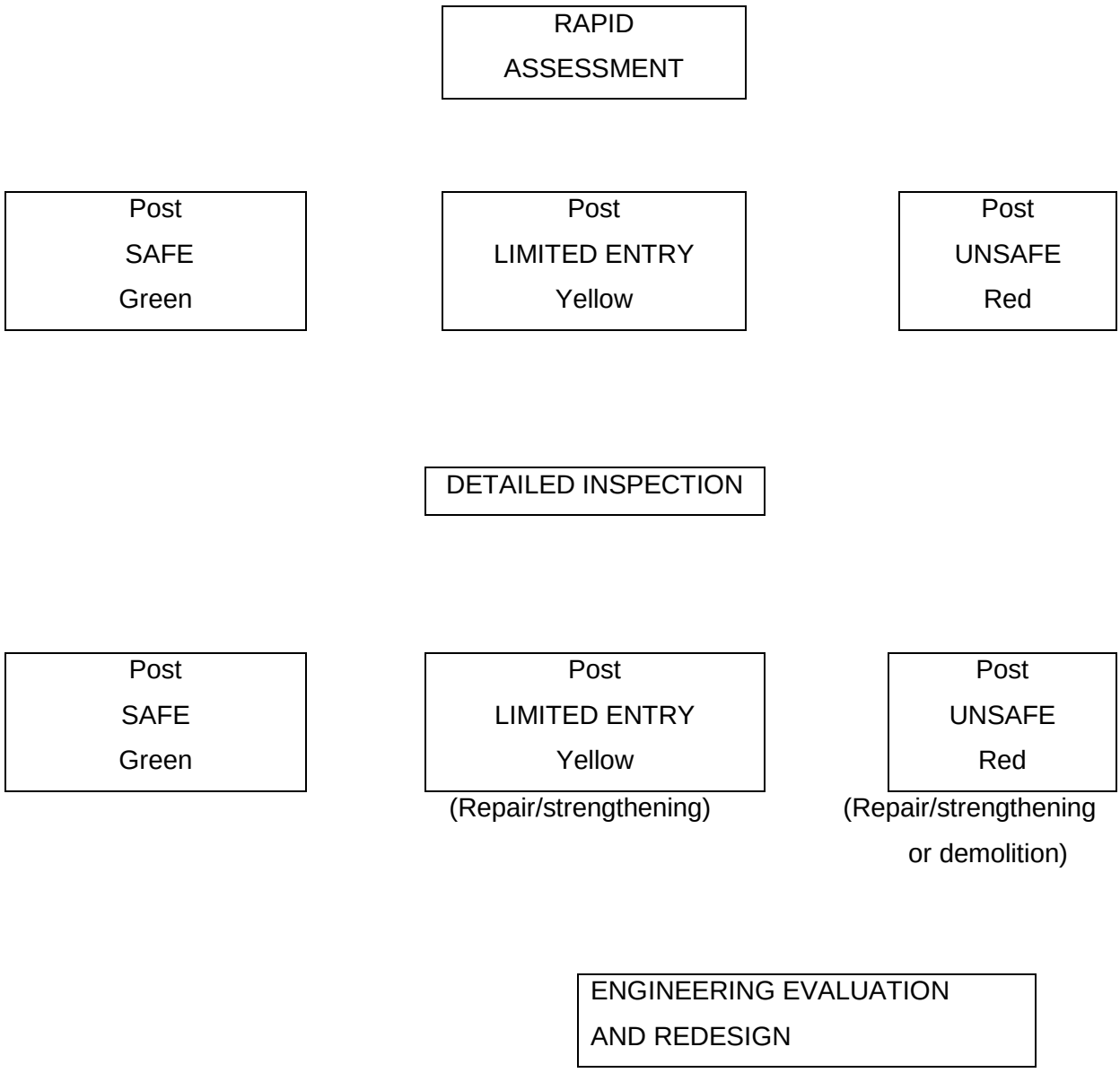

Exhibit 2.1: Procedure for emergency assessment of building safety after a damaging earthquake

SAFE

RESTRICTIONS ON USE AND OCCUPANCY SHOWN BELOW

ADDRESS : .....

CODE No : .....

INSPECTION DATE :..... TIME : .....

INSPECTION TEAM ID:..... SIGNATURE: .....

This building has been inspected as indicated below. No apparent structural damage that would reduce its seismic capacity could be found. Report any unsafe conditions to local authorities; reinspection may be required.

TYPE OF INSPECTION	**RESTRICTIONS ON USE**
EXTERIOR AND GROUND	NO RESTRICTIONS
STOREY	
EXTERIOR, GROUND STOREY	PARTIAL USE .
AND (specify):	LOCAL HAZARDS MARKED
DETAILED	

DO NOT REMOVE THIS PLACARD UNTIL AUTHORIZED BY LOCAL AUTHORITY

Exhibit 2.2: Posting placard for SAFE buildings

LIMITED ENTRY

ENTRY BY UNAUTHORIZED PERSONNEL PROHIBITED

ADDRESS : .....

CODE No: .....

INSPECTION DATE: ..... TIME: .....

INSPECTION TEAM ID: ..... SIGNATURE: .....

WARNING

This building has been inspected as indicated below. It has been damaged and its seismic capacity has been decreased. Enter only at own risk. Aftershocks may result in death or injury.

TYPE OF INSPECTION	RESTRICTIONS ON USE
EXTERIOR AND GROUND	ENTRY FOR EMERGENCY
STOREY	PURPOSES ONLY
EXTERIOR, GROUND STOREY	OTHER
AND (Specify):	
DETAILED	

DO NOT REMOVE THIS PLACARD UNTIL AUTHORIZED BY LOCAL AUTHORITY

Exhibit 2.3: Posting placard for LIMITED ENTRY buildings

UNSAFE

ENTRY PROHIBITED

ADDRESS : .....

CODE No : .....

INSPECTION DATE: ..... TIME: .....

INSPECTION TEAM ID : .....SIGNATURE: .....

WARNING

This building has been inspected as indicated below. It has been seriously damaged and is unsafe. Do not enter. Entry may result in death or injury.

TYPE OF INSPECTION

EXTERIOR AND GROUND STOREY

EXTERIOR , GROUND STOREY AND:

(Specify) .....

DETAILED

DO NOT REMOVE THIS PLACARD UNTIL AUTHORIZED BY LOCAL AUTHORITY

Exhibit 2.4: Posting placard for unsafe buildings

EMERGENCY EARTHQUAKE DAMAGE INSPECTION FORM

BUILDING INFORMATION

1. TOWN: .....
2. ADDRESS: .....
3. SECTION/BLOCK/BCDG No: ...../ ...../ .....
4. POSITION OF BUILDING IN BLOCK □
   1 = Free 2 = Middle 3 = Corner (2 or 3 sides free)
5. BUILDING TYPE □
   1 = Masonry 2 = R. Concrete 3 = Steel
   4 = Wood 5 = Other : .....
6. NUMBER OF STORIES □□
7. USAGE (See back page)
   7.1 BUILDING □□
   7.2 GROUND STORY □□

8. TYPE OF INSPECTION □
   1 = Rapid 2 = Detailed
9. INSPECTION TEAM NUMBER □□□
10. INSPECTION DATE (Day / Month) □□□□

DAMAGE RECORDING

1 = None - Slight 2 = Moderate - Heavy
3 = Severe - Total

11. BEARING WALLS □
12. COLUMNS □
13. BEAMS □
14. FRAME JOINTS □
15. SHEAR WALLS □
16. FALLING HAZARDS (Chimneys, parapets, etc.) □
17. GROUND STOREY AND EXTERIOR WALLS □
18. DAMAGE OF ENTIRE BUILDING □
19. GROUND PROBLEMS □
    1 = None 2 = Settlement 3 = Liquefaction
    4 = Slope movement 5 = Ground fissures
    6 = Rockfalls 7 = Other (Explain below)
20. FURTHER ACTION □
    1 = None 2 = Remove local hazard
    3 = Urgent support required
    4 = Both actions 2 and 3 5 = Urgent Demolition
21. URGENCY: 1 = Low 2 = Medium 3 = High □

COMMENTS:

BUILDING INFORMATION (Additional)

24. NUMBER OF BASEMENTS □□
25. NUMBER OF APARTMENTS □□
26. TOTAL AREA (m^2, approx.) □□□
27. YEAR OF CONSTRUCTION (if known) □□□□
28. TYPE OF STRUCTURAL SYSTEM □□
    (See back page)

ADDITIONAL DAMAGE RECORDING

29. INFILL WALLS □
30. FLOORS AND ROOF □
31. STAIRS □
32. PARTITIONS AND GLAZING □
33. ELEVATORS □
34. HEATING/AC □
35. ELECTRICAL INSTALLATIONS □
36. PLUMBING □
37. INDIRECT DAMAGE □
    1 = None 2 = Pounding 3 = Fire
    4 = Other (explain below)

HUMAN LOSSES (if information available

38. NUMBER OF DEATHS □□
39. NUMBER OF INJURIES □□

POSTING

1 = Green 2 = Yellow 3 = Red
4 = Not posted (explain below)

22. EXISTING □
23. CURRENT □

40. ACTION TAKEN □
    1 = Pending 2 = Partial 3 = Completed
41. INTERVENTION CREW NUMBER □□
42. INTERVENTION DATE (Day/Month) □□□□

COMMENTS

INSPECTOR' S NAME: .....

SIGNATURE:.....

Exhibit 2.5: Emergency Earthquake Damage Inspection Form

USAGE

10 = Residential

20 = Office

30 = Commercial 31 = Small industry

40 = Hospitals/clinics 41 = Social welfare (retirement homes, day care centres, etc.)

50 = Public Services

51 = Police 52 = Fire stations 53 = Communications

54 = Administrative (central or local government) 55 = Transportation

60 = Public Assembly

61 = Schools 62 = Historical and religion 63 = Sports

64 = Culture / entertainment (museums, theatres, music halls, etc.)

70 = Hotels 71 = Restaurants, cafes, etc.

80 = Industrial 81 = Energy

90 = Other Usage (to be specified)

TYPE OF STRUCTURAL SYSTEM

10 = Masonry

11 = Wooden floors and roof, no belts

12 = Wooden floors and roof but with horizontal belts

13 = Concrete floors and roof, no other belts

14 = Concrete floors and roof and additional belts

20 = Wood frame

30 = Reinforced Concrete cast in place

31 = Frame type with brick infills

32 = Frame and shear walls with brick infills

33 = Frame type with lightweight partitions

34 = Frame and shear walls with lightweight partitions

40 = Prefabricated Concrete

41 = Frame type

42 = With panels

50 = Steel frame

60 = Mixed

61 = Composite (Concrete and steel)

62 = Masonry and Concrete

63 = Other (specify)

Exhibit 2.5 (Continued): Emergency Earthquake Damage Inspection Form

3. SAFETY, DAMAGE AND USABILITY CLASSIFICATION

The inspected buildings must be classified in one of the three categories listed in Table 3.1, in which the corresponding criteria, indicative damage and restrictions on usability are also summarised. In accordance with the inspection objectives listed in the previous chapter, the safety of people inside and outside the building is the basic criterion for its classification, for which reference is made to its original seismic capacity. A second criterion is the presence or not of any hazardous condition, which could exist even in buildings whose seismic capacity has not decreased (e.g. damaged parapets, chimneys etc.).

According to Table 3.1, buildings that experienced minor or negligible damage and have no signs indicating a reduction of their original seismic capacity should be posted as SAFE (green colour), provided that no major hazard is present or in case that some local hazard exists, the dangerous area is barricaded and posted “AREA UNSAFE”. Such buildings are usable immediately except for areas, if any, marked “AREA UNSAFE”. At the other end of the spectrum are the heavily damaged buildings, those whose original seismic capacity has greatly decreased and thus are subject to sudden collapse even in minor aftershocks. Such buildings must be posted UNSAFE (red colour), entry in them must be prohibited and the need for emergency support as well as protection of the surroundings must be considered.

Between the SAFE and UNSAFE categories, there will be many buildings with reduced seismic capacity, though not to the extent of been in danger of sudden collapse. Such buildings belong to an intermediate class termed LIMITED ENTRY (yellow colour), and they will require repair and strengthening before they could be occupied on a continuous basis. Although some of them may also need emergency support, the risk when entering them for short periods of time, e.g. for removing valuables, securing contents of apartments etc., is deemed to be low (but not negligible). It should be noted that this is the category with the greatest uncertainty and if the inspector has doubts about his evaluation he should be conservative.

For reliable assessment of the reduction, if any, of a building’s seismic capacity, correct assessment of the damage and of any signs of distress must be made. The guidelines given in the next chapter could provide a good basis for this, but they should always be applied with sound engineering judgement.

TABLE 3.1: SAFETY, DAMAGE AND USABILITY CLASSIFICATION OF BUILDINGS

Posting Classification	Damage State	Usability
SAFE (Green)	**1 = None - Slight**	**Usable - with possible restrictions**
An inspection has shown that the original seismic capacity of the building has not materially decreased and that 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.		
LIMITED ENTRY (Yellow)	**2 = Moderate - Heavy**	**Temporarily unusable**
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.		
UNSAFE (Red)	**3 = Severe - Total**	**Unusable**
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. Decision on possible repair or demolition should be made after an engineering evaluation of technical possibilities and their economic consequences.		

4. DAMAGE ASSESSMENT GUIDELINES

Guidelines for assessing earthquake caused damage in (1) masonry buildings, (2) wood buildings, (3) reinforced concrete buildings, (4) steel buildings and (5) mixed construction buildings are listed in Tables 4.1 through 4.4. These guidelines have been based on experience and engineering judgement and must be applied with care. Photographs indicating various types and levels of damage are also given. It is noted 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. Sound engineering judgement will always be required and the guidelines listed herein must be used as an aid rather than a substitute for such judgement.

4.1. 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.). The guidelines given in Table 4.1 are general enough to cover all cases but it is expected that the structural engineer - inspector will account for the various properties and inherent strengths in making his assessments. Typical damage of masonry buildings is shown in Figs 5 to 12.

4.2. Wood buildings

Wood buildings are used mostly as single family houses in the United States or Japan but not in the earthquake prone countries of Europe. For completeness, however, guidelines for such buildings have also been included in Table 4.2. Typical damage is shown in Figs. 13-18.

4.3. 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-storey residential or office buildings, industrial complexes etc. Concrete construction can be cast in place or precast or a combination of both.

Cast in place concrete buildings constructed before modern codes were introduced (i.e. before ~ 1980) can be quite vulnerable to strong earthquakes, especially if they were built under poor quality control. The majority of multi-storey buildings that have collapsed in catastrophic earthquakes of the recent past belong to this category and are responsible for most of the recorded human loses. 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 rapid strength deterioration that should become visible from the damage of the load carrying vertical members.

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.

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

Guidelines for damage assessment of concrete construction can be found in Table4.3, while pertinent photos are given in Figs. 19-28.

4.4. Steel buildings

Steel buildings are rather rare in seismically active Southern Europe. Field evidence from other parts of the world, however, indicates a generally good behaviour in earthquakes, with very few collapses and hence few lives lost. This is not to say that steel buildings do not suffer damage or that they are not vulnerable. They can be damaged to any degree and the guidelines given in Table 4.4 can be used to assess the level or severity of the damage. It is noted here that in modern steel construction lightweight partitions are normally used and in this respect such buildings are less hazardous than concrete or order steel structures, in which brick or other heavy masonry is used for partitions. Some typical damage of steel buildings is shown in Figs. 29-33.

4.5. Mixed construction buildings

Depending upon the structural types and material combinations, use as an aid to judgement the damage descriptions and guidelines listed in Tables 4.1 to 4.4.

TABLE 4.1 TYPICAL DAMAGE LEVELS FOR MASONRY BUILDINGS (Figures 5 - 12)

DAMAGE LEVEL	DESCRIPTION
1 = None - Slight	1. No signs of any distress 2. Small cracks in partition walls visible from both sides (d $\leq$~2 mm) 3. Small cracks in bearing walls, starting mostly at the corners of a few openings (d $\leq$~ 2 mm) 4. Patches of mortar falling from ceilings or walls 5. Disturbance, partial sliding and falling down of some roof tiles 6. Large cracks or partial failures of chimneys and parapets
2 = Moderate - Heavy	1. Substantial cracking of partition walls (d > ~ 2 mm) 2. Some diagonal cracking in bearing walls (d > ~ 2 mm), but not so extensive as to constitute failure 3. Movement, separation or local failure of roof and floor framing supports 4. Extensive disturbance, sliding and damage of roof tiles in combination with bearing wall damage 5. Collapse of chimneys and parapet walls in combination with bearing wall damage 6. Local heavy damage in some part of the building 7. Minor ground movement
3 = Severe - Total	1. Partial or total collapse 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. Bearing walls with large diagonal or other cracking 6. Fractured foundation 7. Substantial ground movement, dislocation of the whole building or parts of it 8. Any type of damage indicating considerable danger for collapse

Note Falling hazards are cause for marking AREA UNSAFE and for barricading it.

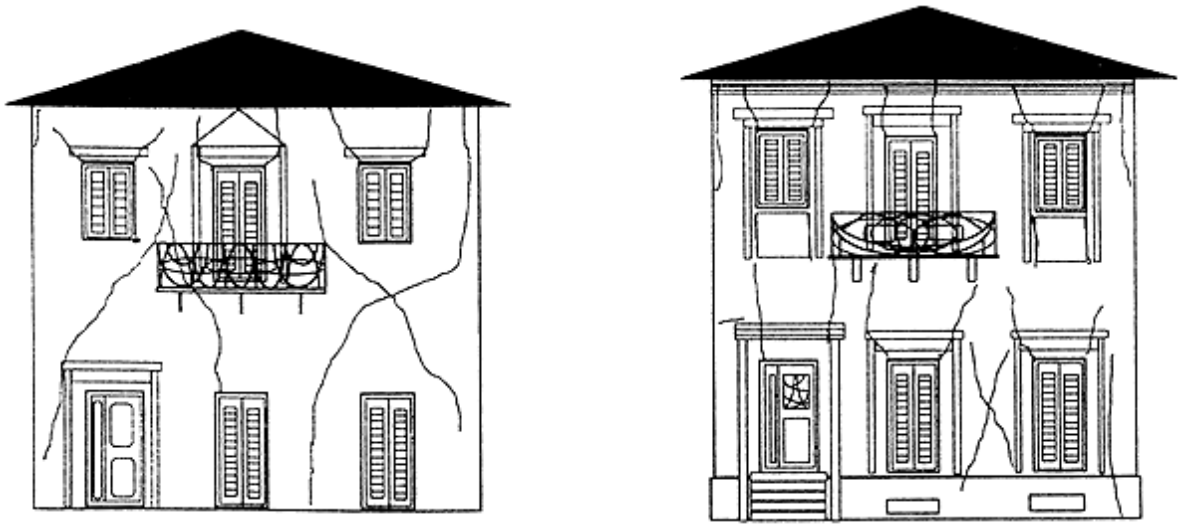

Fig. 5 Typical damage patterns of masonry buildings

Fig. 6 Practically undamaged, 2-storey masonry building (GREEN)

Fig. 7 Slightly damaged, 2-storey masonry building (GREEN)

Fig. 8 Moderately damaged, 2-storey masonry building (YELLOW)

Fig. 9 Moderate to heavy damage of 2-storey masonry building (YELLOW)

Fig. 10 Severe damage of masonry building (RED)

Fig. 11 Partial collapse of masonry building (RED)

Fig. 12 Partial collapse of masonry building (RED)

TABLE 4.2 TYPICAL DAMAGE LEVELS FOR WOOD BUILDINGS

(Figures 13 - 18)

DAMAGE LEVEL	DESCRIPTION
1 = None - Slight	1. No signs of any distress 2. Hairline to small cracking in the plaster of interior walls and in the masonry veneer of exterior walls 3. Some minor residual racking (less than 1.0 cm) of walls 4. Cracks and perhaps partial failures of chimneys
2 = Moderate - Heavy	1. Moderate cracking (~ 2-4 mm) in the plaster of interior walls and in the masonry veneer of exterior walls 2. Moderate residual racking (~ 1.0 to 2.0 cm) of walls 3. Moderate to heavy local damage in a few vertical members and their joints supporting floors and the roof 4. Collapse of chimneys in combination with items 1, 2, 3 above 5. Local heavy damage in some parts of the building 6. Minor cracks in the foundation slab 7. Minor ground movement
3 = Severe - Total	1. Partial or total collapse 2. Partial or total failure of interior and / or exterior walls 3. Large residual racking of walls (greater than 3.0 cm) 4. Floors and/or roof displaced from walls 5. Severe damage in the vertical members and their joints supporting floors and the roof. 6. Separation between two parts of the building 7. Severe to total loss of anchorage to foundation or fractured foundations 8. Substantial ground movement, dislocation of the whole building or parts of it 9. Any type of damage indicating considerable danger for collapse

Note: Falling hazards are cause for marking AREA UNSAFE and for barricading it.

Fig. 13 Damaged 2-storey wood frame building. Lots of broken glass and some lateral offset (YELLOW)

Fig. 14 Local damage to plywood shear wall (YELLOW)

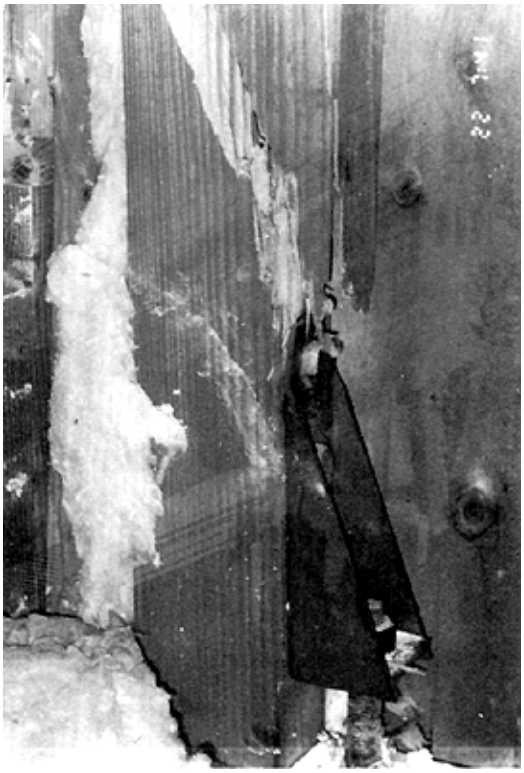

Fig. 15 Fractured post above the holddown (YELLOW)

Fig. 16 Single story wood frame house slipped off its foundation (RED)

Fig. 17 Collapsed 2-story wood frame apartment building (RED)

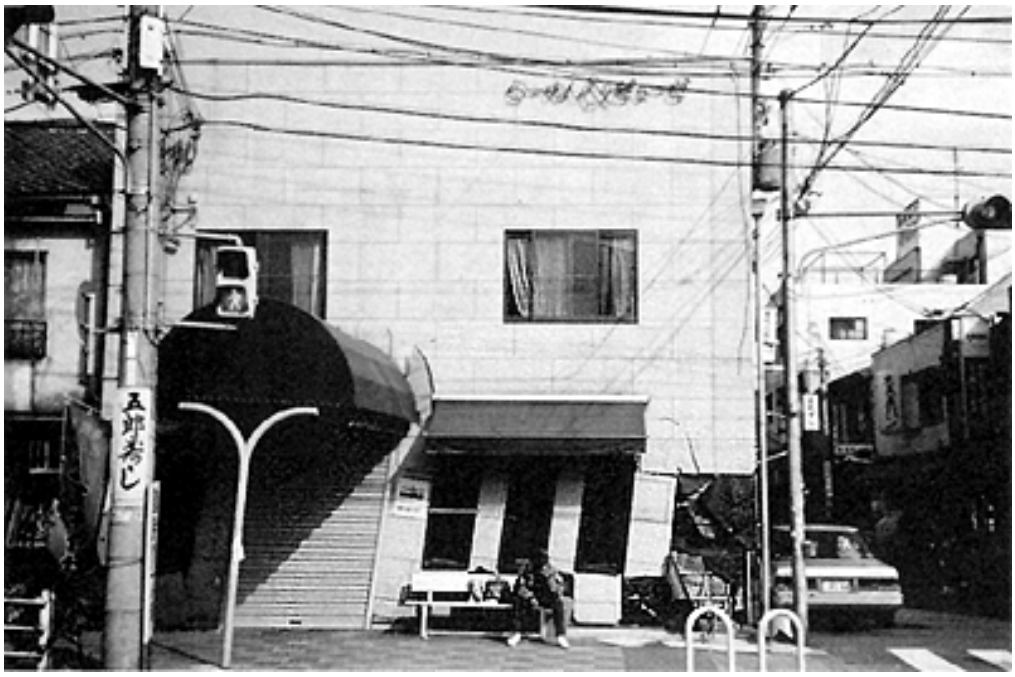

Fig. 18 Large racking of 2-story wood frame building (RED)

TABLE 4.3 TYPICAL DAMAGE LEVELS FOR REINFORCED CONCRETE BUILDINGS (Figures 19 - 28)

DAMAGE LEVEL	DESCRIPTION
1 = None - Slight	1. No signs of any distress 2. Slight structural and non - structural damage 3. Fine cracks in wall and ceiling mortar 4. Small cracks in a few infill or partition walls 5. Hairline cracks in some structural elements (beams, slabs, joints, columns) and in connections of prefabricated buildings 6. Disturbance, partial sliding or falling down of roof tiles 7. Large cracks or partial failures of chimneys and parapets
2 = Moderate - Heavy	1. Substantial to large diagonal or other cracking in partition or infill walls in one or more storeys. Detachment or partial failure of such walls. 2. Small to large cracks ($d \leq 5$ mm) in beams and joints and in connections of prefabricated buildings, smaller cracks in columns and shear walls ($d \leq 3$ mm) 3. Spalling of concrete from structural members, exposure of reinforcement, crushing of material in certain locations but to an extent that it does not constitute a danger for collapse 4. Extensive disturbance, sliding and damage of roof tiles in combination with other damage listed herein 5. Collapse of chimneys and parapets, in combination with other damage listed herein 6. Local heavy damage in some part of the building 7. Slight dislocation of structural elements 8. Minor ground movement but no signs of foundation failure
3 = Severe - Total	1. Partial or total collapse 2. Widespread infill failure or severe cracking extending to the concrete elements in one or more storeys

(CONTINUED)

3. Large number of crushed structural elements and connections, exposure and buckling of reinforcement in several locations
4. Considerable dislocation of structural elements, residual drift in any storey or dislocation of the whole building
5. Substantial ground movement, uplift of footings or fracture of foundation beams, fracture or bowing of basement perimeter walls etc.
6. Any type of damage indicating considerable danger for collapse

Notes: 1. Falling hazards are cause for marking AREA UNSAFE and for barricading it.

2. In prefabricated buildings, attention should be given to the connections of structural elements, to the regions of floor or roof support and to possible residual displacements of vertical elements (wall panels or columns).

Fig. 19 Undamaged R/C building (GREEN)

Fig. 20 Minor cracking in brick infills of R/C building (GREEN)

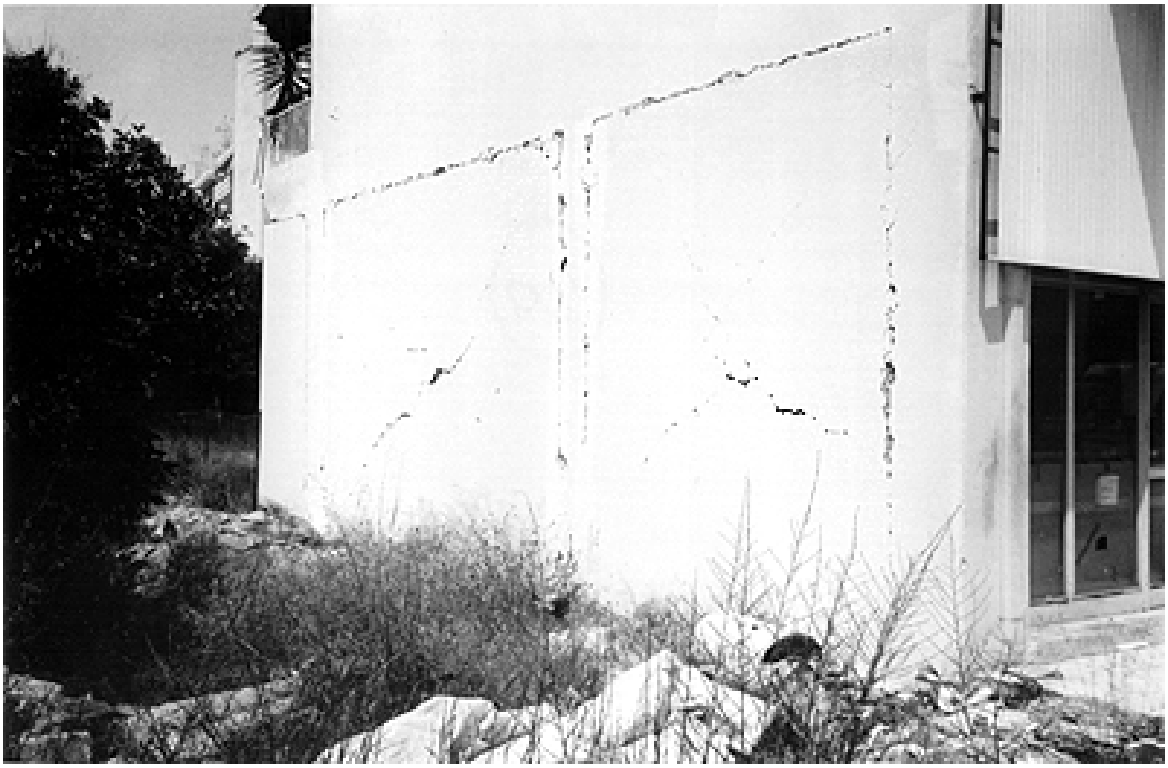

Fig. 21 Cracking and separation of brick infills of R/C building (GREEN)

Fig. 22 Local heavy damage in short columns of R/C building (YELLOW)

Fig. 23 Fracture of one column (others OK) and several cracked infills of a R/C building (YELLOW)

Fig. 24 Severe cracking of several interior brick infill walls in a R/C building (YELLOW)

Fig. 25 Heavy infill damage, minor damage in R/C elements (YELLOW)

Fig. 26 Crashed R/C columns (several) and dislocation of building (RED)

Fig. 27 Ground problems accompanied by heavy structural damage in R/C columns (RED)

Fig. 28 Ground story collapse and tilt of a 2 ½ story R/C building (RED)

TABLE 4.4 TYPICAL DAMAGE LEVELS FOR STEEL BUILDINGS

(Figures 29 - 33)

DAMAGE LEVEL	DESCRIPTION
1 **= None - Slight**	1. No signs of any distress 2. Hairline or small cracking in the plaster of partition walls and in the masonry veneer of exterior walls 3. Minor damage in the ceilings, lighting fixtures etc. 4. Minor damage in the cladding (partial dislodgement, some broken glass) 5. Some minor residual racking (less than 1.0 cm) of walls 6. Negligible to slight structural damage (signs of distress in some structural members and their connections) 7. Cracks and perhaps partial failures of chimneys
2 = Moderate - Heavy	1. Moderate cracking (~ 2 - 4 mm) in the plaster of interior walls and in the masonry veneer of exterior walls 2. Moderate residual racking (~ 1.0 to 2.0 cm) of walls 3. Moderate to heavy damage in ceilings (dislodgement of suspended ceilings, disattachment of lighting fixtures etc.) 4. Moderate to heavy damage in the cladding (dislodgement and partial failure of panels, plenty of broken glass etc.) 5. Moderate to heavy local damage in structural members and connections (a few buckled or broken braces, flange buckling in a few columns, slippage or cracks in some base plates, weld or other connection failure in a few joints, movement or failure at some shear connections between floor diaphragms and beams, etc. 6. Collapse of chimneys and parapets in combination with other damage listed herein 7. Slight dislocation of structural elements 8. Minor ground movement but no signs of foundation failure
3 = Severe - Total	1. Partial or total collapse

(CONTINUED)

2. Widespread failure of interior partition walls, cladding and glass
3. Many failed structural members, joints and connections (buckling or stretching of braces, buckled column flanges, slippage or cracks in many base plates, many cracks in welded connections, cracked bolts and gusset plates etc.)
4. Considerable dislocations of structural members, residual drift in any storey or dislocation of the whole building
5. Substantial ground movement, fructure of base slab, or bowing of basement perimeter walls
6. Any type of damage indicating considerable danger for collapse

Note: Falling hazards are cause for marking AREA UNSAFE and for barricading it.

Fig. 29 Four story steel building with extensive broken glass and several buckled braces (YELLOW)

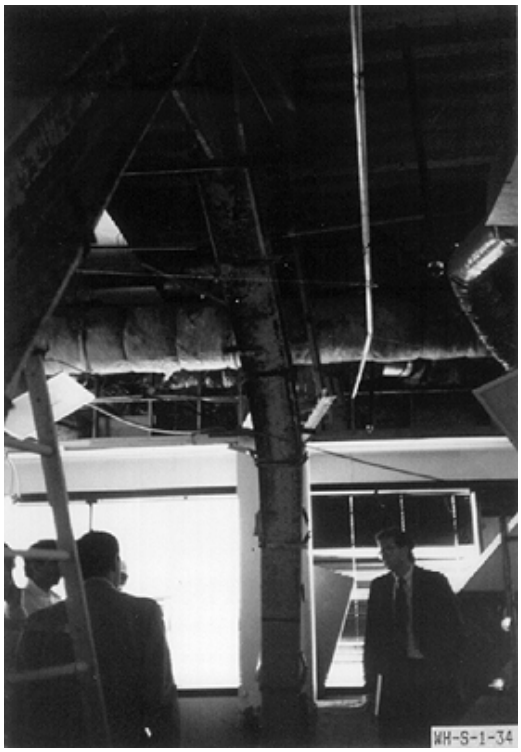

Fig. 30 Buckled brace of building in Fig 29

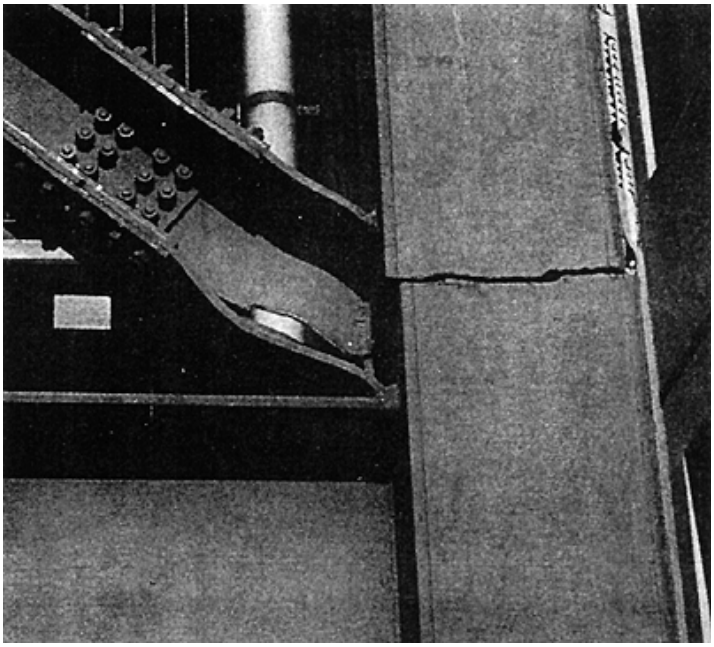

Fig. 31 Complete column fracture and brace failure (YELLOW)

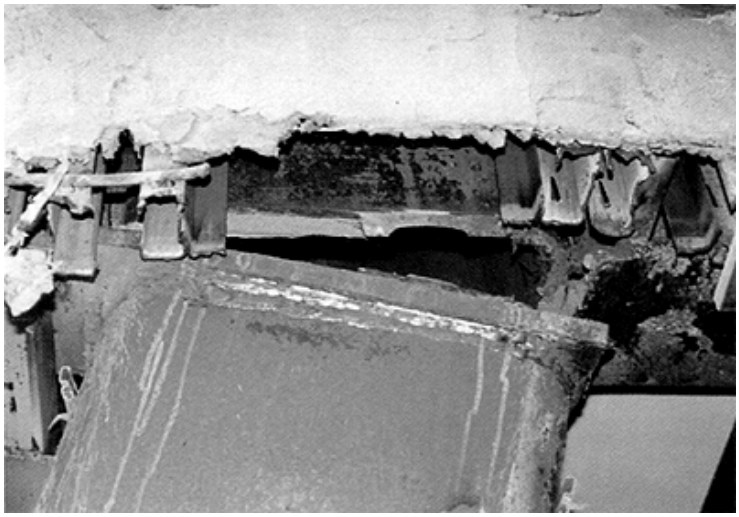

Fig. 32 Fractured weld of the panel plate in beam - column joint (YELLOW)

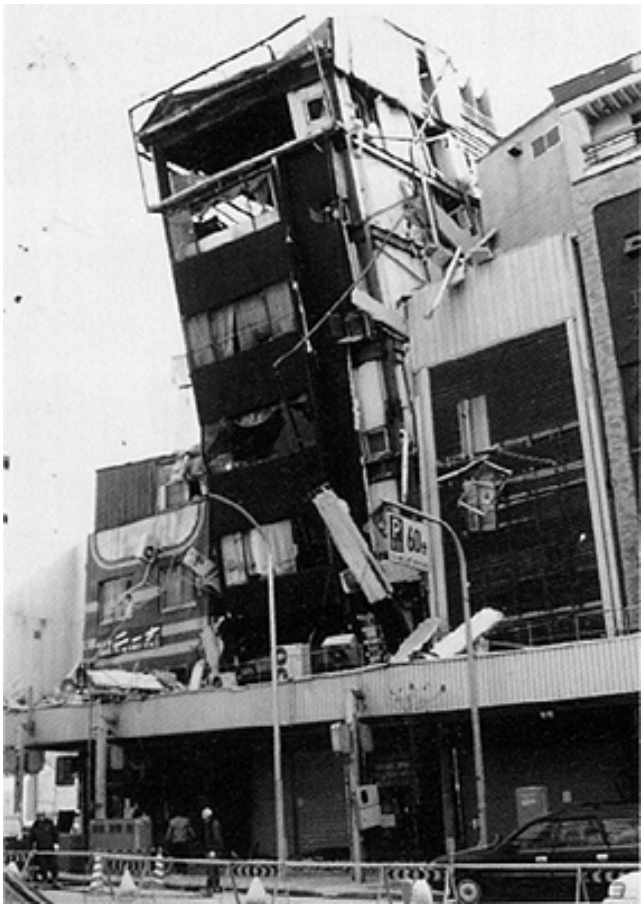

Fig. 33 Failed 7-story braced steel frame building (RED)

5. BUILDING INSPECTIONS

The procedures described in this manual are based on two types of building inspections: a rapid and a detailed one. The rapid inspection is easier to carry out and requires less time and less experience than the detailed evaluation. It is aimed at quickly identifying obviously safe or unsafe buildings, according to the classification criteria listed earlier. The detailed evaluation, on the other hand, will be required for critical facilities and important structures and also for all those buildings that may have been weakened by the earthquake, but the hazard, if any, associated with them could not be identified from a rapid inspection. Prior experience in detailed evaluations, although not a requirement, can be quite important for reliable assessments.

5.1. Rapid assessment

Purpose

The rapid assessment is carried out to quickly screen the obviously safe and obviously unsafe buildings, thus minimising the number of those buildings that need a more time consuming detailed inspection.

How it is done

1. Fill in entries 1 to 10 of the Emergency Earthquake Damage Inspection Form (EEDIF)
2. Examine visually:
    - The outside of the building (all sides that are easily accessible).
      Look for signs of residual drift (building or parts of it out of plumb), damage to chimneys and roof, to exterior walls, to the facade etc.
    - The ground storey, whether open (pilotis) or built. **Obviously unsafe structures should not be entered.**
      Look for damage to all visible structural elements, especially columns, shear walls, core elements, beams and stairways. Look for potential residual movement at the base of vertical elements. Also check all infill or partition walls.

- Any part of the building for which the occupants report significant damage. **Obviously unsafe structures should not be entered.**
- The ground around the building.

  Look for settlements, ground fissures, signs of liquefaction and, in case of hillside buildings, for signs of slope movement and rockfall hazards.

3. On the basis of the visual inspection and with the indicative damage descriptions in Tables 4.1 to 4.4 as a guide, fill in entries 11 to 17 of the EEDIF and subsequently entries 18, 19 and 20, using proper engineering judgement.
4. Fill the POSTING section of the EEDIF.
   - If both entries 18 and 19 are 1, mark 1 (GREEN)
   - If either entry 18 or 19 is 2, mark 2 (YELLOW)
   - If either entry 18 or 19 is 3, mark 3 (RED)
5. Post the building and barricade any unsafe areas.
   - Post the building according to the results of the assessment. Fill, and sign the appropriate placard (SAFE, LIMITED ENTRY or UNSAFE) and post every entrance.
   - If some local hazard is present (entry 16 in the EEDIF marked 2 or 3), barricade the unsafe area and post it as AREA UNSAFE.
   - Discuss the purpose and meaning of the posting with the occupants of the building and advise them accordingly. In particular, explain that this inspection will not be used as the basis for receiving financial aid for repair works.

Estimated time

Spend no more than 10-30 minutes per building.

Tips

- Look first for obvious signs of total building distress (partial collapse, l eaning buildings, fractured structural members, ground and foundation problems).
- Examine then the ground storey but only if it is safe to do so.
- Post RED obviously unsafe buildings without entering them.

- Building occupants are a good source of information about the damaged areas.
- If the ground storey is open, look for damage in the structural elements and assess them accordingly.
- In case of doubts be conservative and ask for a detailed inspection.
- Pay special attention to the recommendations for further action.

5.2 Detailed evaluation

Purpose

The detailed evaluation is carried out for all buildings posted yellow from a rapid assessment, for all critical facilities (hospitals, police and fire stations, communication buildings, etc) and other important structures (e.g. schools, assembly halls etc.). It is aimed at providing a more reliable estimate of the condition of the building, given that the yellow posting is used for buildings that are not obviously safe or unsafe and hence there is doubt about their condition.

How it is Done

1. Fill in entries 1 to 10 of the EEDIF
2. Examine from outside (before entering the building):
   - All sides of the building that are accessible. Look for signs of residual drift (building or parts of it out of plumb), damage to chimneys and roof, to exterior walls, to the facade etc.
   - The site for ground problems or geological hazards. Look for settlements, ground fissures, signs of liquefaction and, in case of hillside buildings, for signs of slope movement and rockfall hazards.
3. Examine the building interior:
   - Before entering the building look for any type of life threatening hazards. **Do not enter obviously unsafe buildings.**
   - Determine the type of structural system and fill in entry # 27 of the EEDIF. Look at exposed areas such as open ground storeys (pilotis), basements, stairwells or mechanical floors.

- Proceed from the ground storey upwards and inspect every floor including penthouse and roof. Examine all visible structural elements, paying special attention to the vertical members (columns, shear walls) and to any observable residual drift. Move removable panels to view structural components, but do not do any destructive exploration other than local plaster removal to check whether cracks in infill walls extend to the adjacent structural elements. Inspect for non-structural damage and take note of any potential hazards.
- Inspect the basement for foundation problems, uneven settlements, fractured slabs, displaced columns at base and fructured or bowing perimeter walls.
- Inspect stairs and elevators and if elevator damage is suspected make sure that its power is shut-off.
- Look for spills in areas where chemicals or other hazardous materials are stored.

4. On the basis of the detailed inspection and with the indicative damage descriptions in Tables 4.1 to 4.4 as a guide, fill in entries 11 to 17 and 28 to 37 of the EEDIF and subsequently entries 18, 19 and 20, using proper engineering judgement.

5. Fill in entries 23 to 26 and 38, 39 on the right of the EEDIF, if the required information is available, and proceed with posting.
   - If both entries 18 and 19 are 1, mark 1 (GREEN)
   - If either entry 18 or 19 is 2, mark 2 (YELLOW)
   - If either entry 18 or 19 is 3, mark 3 (RED)

6. Post the building and barricade any unsafe areas.
   - Post the building according to the results of the assessment. Fill and sign the appropriate placard (SAFE, LIMITED ENTRY, UNSAFE) and post every entrance. If the building was already posted following a rapid assessment, replace the old placards.
   - If some local hazard is present (entry 16 in the EEDIF marked 2 or 3), barricade the unsafe area and post it as AREA UNSAFE.

- Discuss the purpose and meaning of the posting with the occupants of the building and advise them accordingly. In particular, explain that this inspection **will not be used as the basis for receiving financial aid for repair works.**

Estimated time

Depending on the size of the building, it is anticipated that a detailed inspection could take anywhere from one to three hours.

Tips

- Make every effort to identify the type of structural system and the load transfer mechanism for gravity and earthquake loads.
- In concrete buildings with masonry infills, the infills are the first line of defence, followed by elevator core or shear wall elements, if any, while the frame comes last. It is not uncommon with such buildings to have heavily cracked infills and no visible damage in the main structural elements. Since their seismic capacity is obviously reduced, such buildings are cases that would normally be posted YELLOW.
- Look for obvious signs of total building distress (partial collapse, dislocated or leaning building) and for foundation or ground problems.
- Discontinuities in plan or in elevation should be paid proper attention, as they are points of stress concentration and hence candidates for damage.
- Building occupants are a good source of information about damaged areas.
- Pay special attention to the recommendations for further action

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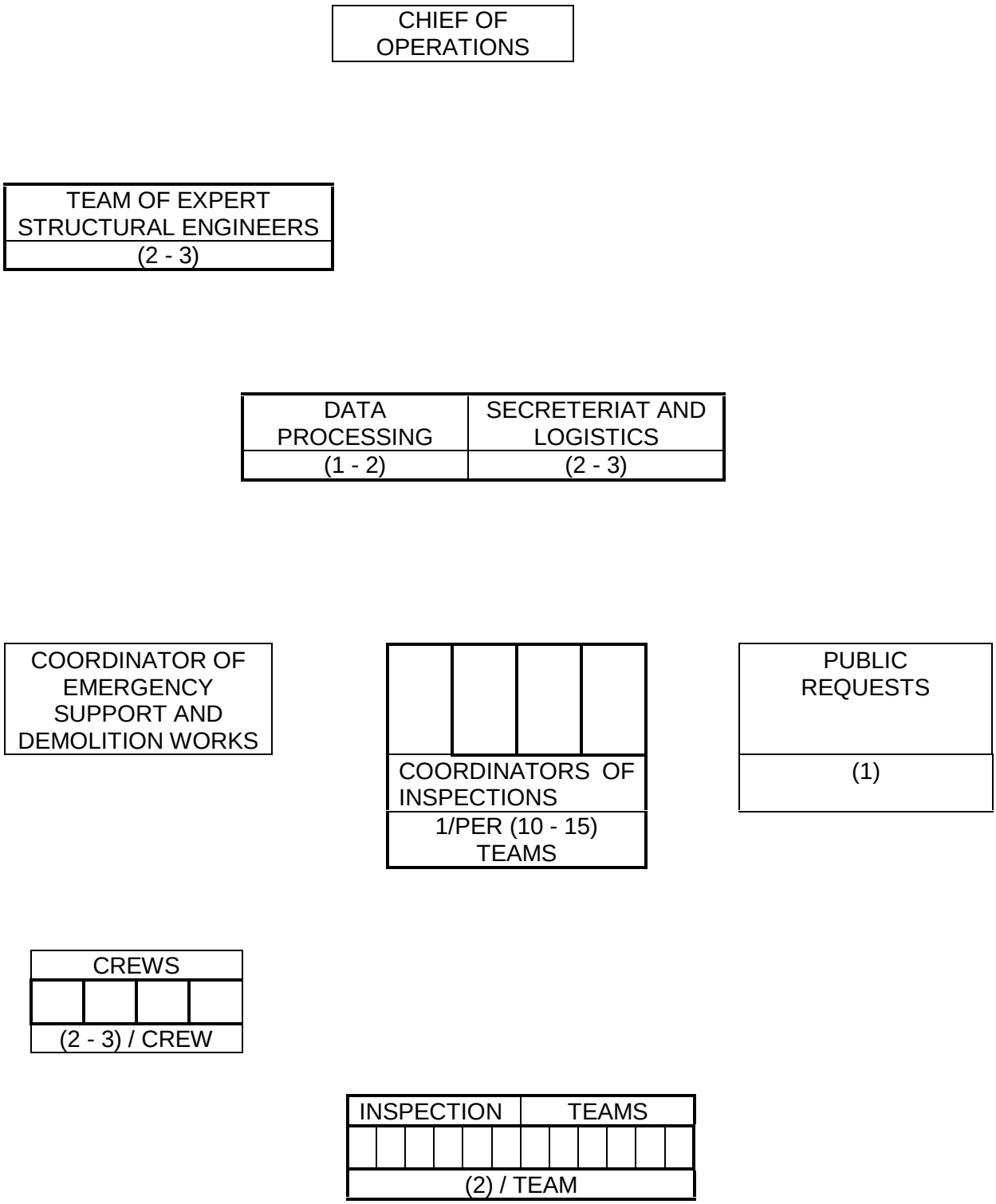

Note: Indicative numbers of personnel shown in parentheses

Exhibit 6.1: Organisational structure for a large scale emergency earthquake damage inspection operation

5.3 Reinspections

The need for reinspection will arise in the event of aftershocks that could change the condition of buildings already inspected. In addition, reinspection will be required for buildings marked for demolition but their owners refuse their consent or when any owner requests a reinspection by submitting proper justification.

After damaging aftershocks, the reinspections will be carried out in the normal mode of operation and by checking only buildings in the green and yellow categories. Since the strongest aftershocks occur within a few hours to a few days after the main event, the number of buildings that might have been inspected by then and which will require reinspection will normally be small. Reinspections by an expert team are envisioned for those buildings marked for demolition and for which the owners do not give their consent (see also chapter on legal issues).

Reinspection could also be requested by individual owners who may have reasons to believe that the posting given to their building is not correct. In such cases, however, and in order to avoid an excessive number of requests, the pertinent application should include the signed opinion of a licensed professional structural engineer providing the arguments in support of the request

6. OPERATIONAL PLAN

This operational plan is intended to be used as a blueprint for organising emergency damage inspections of buildings in populated areas stricken by a catastrophic earthquake. It is tailored around the procedures recommended herein, drawing also on experience gained from earthquakes in Greece during the past 20 years. Such a plan will be part of a more general preparedness plan, designed to deal with the emergency created by an earthquake. Therefore, the details of its implementation will depend upon this general preparedness plan and thus could vary from one country to another. However, its main elements would not need to change, if the underlying inspection procedures remain the same.

6.1. Organisational Structure

An essential element for the success of the operation is its organisational structure. Based on past experience, the structure shown in Exhibit 6.1 is recommended. It is appropriate for small as well as large scale operations and if it is properly prepared within the general predisaster planning activities it can produce the desirable results.

6.2. Tasks and responsibilities

The following describe the tasks and responsibilities of the different people involved in the operation, according to the organisation al structure shown in Exhibit 6.1.

A. Chief of operations

1. Directs the setting up of the operation
    - Secures personnel.
    - Assigns duties.
    - Sets up local field office.

2. Directs the operation
   - Specifies priorities.
   - Oversees work progress.
   - Chairs meetings with coordinators.
   - Approves / changes daily work programme.
   - Decides on tasks for the team of experts.
   - Resolves conflicts.
   - Communicates with other emergency officials and with authorities.
   - Replaces personnel for poor performance, lack or co-operation etc.
   - Gives pertinent information to the appropriate authorities

3. Submits a final report to the appropriate authorities.

B. Coordinator of inspectors

1. Coordinates and supervises the work of 10 to 15 inspection teams.
2. Names the leader of each team.
3. Assigns the areas of responsibility for each team.
4. Secures the availability of materials for the inspection teams.
5. Receives the damage inspection forms and ranks the degree of urgency of the required actions.
6. Makes spot checks of inspected buildings.
7. Gives copies of the damage inspection forms for data processing.
8. Participates in the end - of - the - day meeting with the chief of operations and the coordinator of the support and demolition crews to prepare the intervention list for next day, review progress, solve problems etc.
9. Resolves conflicts between his teams.
10. Seeks the assistance of the team of experts teams if the need arises.

C. Coordinator of emergency support and demolition crews

1. Coordinates, directs and supervises the work of the emergency support and demolition crews.
2. Names the leader of each crew.
3. Assigns the work to the crews.

4. Secures the availability of tools, equipment and material for his crews.
5. Participates in the end - of - the - day meeting with the chief of operations and the inspection team coordinators to prepare the intervention list for next day, review progress, solve problems etc.
6. Provides technical advice and checks the work of his crews in the field.
7. In consultation with the chief of operations seeks additional technical assistance, if his crews are not sufficient.
8. Seeks the technical advice of the team of experts in difficult situations.
9. Resolves conflicts between the crews.
10. Gives the daily list for intervention as well as progress information to the data processing unit.

D. Damage inspectors

1. Inspect the buildings, fill the damage inspection forms, barricade unsafe areas, mark them and post the buildings with the appropriate placard.
2. Explain to the building occupants the safety reasons for the inspection and the meaning of the posting. Make clear that this inspection has nothing to do with the detailed engineering evaluation and design that will be required to receive any governmental assistance for possible repairs.
3. The leader of the team signs the posting placard and the damage inspection form. In case of disagreement with the second member of the team, his opinion prevails.

E. Data processing

1. Process the data on the damage inspection Forms.
2. Produce lists with requirements for further action.
3. Produce summary reports.

F. Secretariat and Logistics

1. Provide clerical and secretarial support to the operation.
2. Maintain stock and supply the materials required for the operation (see list), except for the materials needed for emergency support and demolition.

G. Public requests

1. Handles requests by the public (e.g. provides inspection scheduling information, receives and processes information about emergency conditions, explains safety classification, gives information about government assistance for repairs etc.).
2. Assists the secretariat and logistics unit.

6.3. Operation setup checklist

The following is a checklist of the necessary actions to set up the emergency earthquake safety inspection operation.

1. Mobilisation. Chief of operations, designated in the general emergency mobilisation plan, receives order.
2. Chief of operations:
   - Assigns duties to support personnel (secretarial, data processing etc.).
   - Names inspection team coodinators, coordinator of emergency support and demolition works and a deputy chief.
3. Set up of local field office:
   - Secure housing or temporary shelter for the operation.
   - Secure telephones, office furniture and supplies.
   - Secure 1 copying machine, 2 PC’s and 2 printers.
4. Form inspection teams and assign ID numbers.
5. Form emergency support and demolition crews.
6. Briefing of all personnel about the operation, tasks etc.
7. Secure the availability of tools, equipment and emergency support materials.
8. Bring in and distribute material required by the inspection teams.
9. Divide the stricken area into sections and number blocks and buildings (if this has not been provided for in the general preparedness plan).
10. Start rapid assessments.

11. Begin detailed inspections starting with critical facility buildings.
12. As inspection data starts coming in, mobilise emergency support and demolition crews.
13. Utilise the team of experts for important structures, difficult assessments etc.
14. Repeat inspections after major aftershocks.

6.4. Human resources

The operation will be carried out mostly by people working for the city and local or state government. Volunteer structural engineers from the private sector may also be used as inspectors, if the available pool of structural engineers working for the public sector does not suffice. This will normally be the case if the earthquake strikes a major city. Under such circumstances, cooperation with engineering professional associations will help alleviate the problem.

A. Chief of Operations

The person who will assume the post of operations chief should be a structural engineer official with the Building Department having jurisdiction over the affected area. Alternatively, and depending upon the administrative structure of each county, the chief of the operation could be a senior structural or civil engineering official of the city, the prefecture etc. He should have a good leadership record, should be familiar with the problem and also quite knowledgeable of the emergency mobilisation plan and the bureaucratic machinery that will support the operation. The above should be considered by the emergency agency planners that prepare the general mobilisation plan, in which the official who becomes chief of operations will be designated.

B. Coordinators for emergency inspections and intervention

The coordinators of the inspection teams and the coordinator of emergency support or demolition works should be experienced structural engineering officials of the city or the governmental agencies involved in this operation. They should also be familiar with the mobilisation plan and the bureaucracy of the agencies supporting the operation.

C. Damage inspectors

Damage inspectors constitute the back bone of the operation. They should be in teams of two inspectors, one of whom will be the leader of the team. They should be structural engineers, employees of the city or local government in the affected area, neighbouring jurisdictions or from other areas in the country having pertinent experience from past earthquakes. If their numbers are insufficient, local volunteer professionals could also be commissioned and utilised, with the assistance of the appropriate professional associations.

E. Emergency support and demolition crews

They should be structural works technicians, equipment operators and structural workers. They should come from the agencies involved in this operation (e.g. building departments, city technical services, public works department etc.) or, if not sufficient in number, from the private sector.

F. Team of experts

They should be senior structural engineers from the public or private sector, well recognised for their earthquake engineering and damage assessment expertise.

G. Data processing, secretarial and logistics personnel

The support personnel comes from the departments or agencies to which the chief of operations or the coordinators belong or from any other department, as foreseen in the emergency mobilisation plan.

6.5. Material and equipment

Advance planning of the post - event inspections operation is a key element for its success. Such planning should include the advance preparation and stocking of essential items, e.g. city maps, damage inspection forms etc. In addition, the availability of demolition equipment should be secured as well as its operators. The

following is a list of materials that should be readily available for running the operation smoothly.

A. Local field office

1. Desks and chairs.
2. Telephone equipment.
3. Photo copying machine.
4. 2 Personal Computers for running the operation support program.
5. 2 printers.
6. Topographic maps of the community on a scale 1:10000 or 1:5000.
7. Topographic maps of the community on a scale 1:1000, showing street names, block numbers and, if possible, building ID numbers.
8. Adequate stock of posting placards, damage inspection forms and field manuals.
9. Barricading tape (red - white stripes).
10. Notebooks, pens, pencils, etc.

B. Essential items the inspectors should carry:

1. Topographic maps (1:1000) with block & building numbers.
2. Hard hat.
3. Measuring tape/meter.
4. Flashlight and extra batteries.
5. Carpenters ax or hammer.
6. Posting placards, inspection forms, a field manual and barricading tape.
7. Notebook and pen.
8. Official identification.

C. Other suggested, items for inspectors

1. Camera with flash and several roles of film.
2. Binoculars.

Tools and equipment for the hazard removal and demolition crews should be provided by the city or local government technical services or other pertinent departments. If the available equipment (bulldozers, cranes etc.) from the public sector is not sufficient, it could be supplemented from the private sector. For operational efficiency, this should be provided for in the general mobilisation plan, in which updated lists of the required equipment, its owners and operators should be maintained.

7. FIELD SAFETY OF INSPECTORS

The inspectors assessing the safety of a building damaged by an earthquake must be careful not to expose themselves to hazardous conditions. Quite often, a building that has suffered serious, but not always readily observable, structural damage from the main shock may be in danger of collapse in the event of an aftershock. Therefore, the basic safety rule that inspectors must always observe and which has been emphasised throughout this manual, is not to enter a building, unless they feel it is safe to do so. This requires a careful survey of the building exterior for a gross assessment of the building's condition. In addition to this, several other precautions as explained below should be taken.

Inspectors should work in pairs, not only for reaching more reliable assessments by exchanging views when in doubt, but also for having one team member provide assistance or call for help in case the other member is injured. When entering a damaged building, inspectors must be well equipped, wearing their hard hats and in constant alert for aftershocks, falling hazards (parapets, glazing, appendages, ornamentation etc.) or leaks of hazardous substances. In case they enter a factory, laboratory or storage area, they should be quite careful to recognise any suspected hazardous material release either from sighting damaged containers and spills or by odor, eye irritation, breathing problems etc, all of which constitute warnings for potential chemical hazard. In such cases the inspectors should exit from the suspected area, take note and inform the field office immediately. Damaged utility installations, such as electrical or gas, may also constitute serious hazards, e.g. in cases of exposed electrical wiring or when there are gas leaks. Gas can usually be detected by odor and if this situation is encountered an effort should be made to locate and shut off the main valve. Obviously the inspectors should refrain from smoking when entering such premises and it is prudent to do so also when entering any damaged building.

In summary, the main precautions that inspectors should take when carrying out their field work are:

1. Travel and inspect in pairs.
2. Wear always a hard hat while in a damaged building or in its surroundings.
3. Survey carefully the building exterior before entering and enter only if deemed safe to do so.
4. Be alert for aftershocks and prepared to take cover when one comes.

5. Inspect carefully for falling hazards (e.g. parapets, glazing, ornamentation etc.) and do not take risks attempting to remove them.
6. Be alert for damaged utility installations, avoid exposed electrical wiring or downed power lines and try to shut off the electricity and gas supplies.
7. Be alert for leaks of hazardous (toxic or other) substances and avoid all areas where the presence of such substances is suspected.
8. Do not use elevators.
9. Play it safe whenever in doubt about something that may entail risk.

8 LEGAL ISSUES

When the emergency inspections operation is planned (before a catastrophic earthquake strikes), the responsible authorities should take all necessary legislative steps to extend full insurance coverage to the personnel that will be involved in the inspections for the period the operation lasts. This may be done either by conferring upon such personnel a temporary status of state or city employee for the period of the inspections and thus extend to them all the pertinent coverages or by instituting specific provisions. Under all circumstances, the inspectors should be free, by law, of any liability that may arise as a result of their posting or, more generally, in the course of carrying out the inspections. This is a necessary measure to ensure objectiveassessments and avoid systematic conservatisms out of fear of liability in the event of damages that may result from the posting decision.

Another part of the operation that requires well instituted legal procedures has to do with the emergency demolitions that will be carried out during the operation. While some damaged buildings may constitute an obvious hazard and thus require immediate removal, there will often be cases that the need for demolition could be debated. To avoid subsequent litigation, it is necessary to have adequate and well thought legal procedures that will allow the demolition crews to act quickly for protecting public safety, while at the same time securing all the rights of the property owners. Thus, buildings marked for demolition as been hazardous to the public should be reinspected by an expert team and the owner’s consent should be sought before any actionis taken. If the owner refuses to give his consent, he should be instructed to either remove the hazard on his own or face all the consequences for subsequent damages that may result from his hazardous property.