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LARGE SCALE OPERATIONS FOR POST-EARTHQUAKE, EMERGENCY ASSESSMENT OF BUILDING SAFETY

S.A. ANAGNOSTOPOULOS

Department of Civil Engineering, University of Patras, 26500 Patras, GREECE

ABSTRACT

Post-earthquake damage evaluation and assessment of building safety is a prerequisite for emergency measures necessary for mitigating the consequences of catastrophic earthquakes as well as saving human life from possible aftershocks. Buildings that are safe, despite perhaps some minor damage, could be quickly used and thus reduce the number of homeless people and the associated pressing problems. When the affected area is a major city, there may be thousands of buildings whose safety must be evaluated, calling for an operation that constitutes a major undertaking. The purpose of this work is to present the essentials of such an operation and to put forward recommendations that could contribute to its success. These are based primarily on careful review of the accumulated collective experience from past earthquakes in several countries and on identification of various sources on difficulty, causes of inefficiency etc. It is concluded that it is possible to have uniform and reliable evaluations of building safety under post-earthquake conditions of emergency, provided that correct criteria, procedures and logistics have been elaborated in advance and that they incorporate any available past experience. It appears also that two level inspections, rapid and detailed, combined with correctly designed damage inspection forms with clearly spelled guideline can substantially improve efficiency and assessment quality.

KEYWORDS

Building damage; damage assessment; emergency; hazard; post-earthquake inspection; safety; posting.

OBJECTIVES AND TASKS OF THE OPERATION

The operation of emergency inspections of damaged buildings should start within hours, if possible, after the earthquake strikes. 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 optimize their time and efforts. Ranked by their importance, these objectives are:

1. Protect human life.
2. Indicate unsafe areas around hazardous buildings and identify temporary shelter sites.
3. Save properties.
4. Minimize : (a) the number of homeless and (b) the loss of economic activities.
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, in order to eliminate them through appropriate modifications in existing codes and construction practices.

The main tasks of such operations 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.

To be successful in meeting its objectives, the operation must be well organized, so that it is completed in a short period of time, while securing uniformly reliable damage and safety assessments as well as quick processing of data and prompt actions.

SAFETY, DAMAGE AND USABILITY CLASSIFICATION

The inspected buildings must be classified in one of the three categories listed in Table 1, in which the corresponding criteria, indicative damage and restrictions on usability are also summarized. In accordance with the inspection objectives listed above, 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.).

Table 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 nonstructural 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.		

According to Table 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 color), 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 color), 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 color), 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 e.t.c, 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. This can be achieved following representative damage descriptions and criteria developed for various types of buildings (e.g. Anagnostopoulos et al, 1989, ATC-20, 1991). An example of pertinent guidelines for reinforced concrete buildings is given in Table 2. In using them, however, it should never be forgotten that such guidelines must always be viewed as an aid rather than a substitute of engineering judgment.

Table 2. Typical Damage Levels for Reinforced Concrete Buildings

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
	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).

OVERVIEW OF THE OPERATION

The emergency inspections operation includes, in addition to the inspections, posting of the buildings according to their safety classification, as well as emergency interventions for hazard removal or shoring and bracing of heavily damaged buildings.

Inspections and posting

The emergency inspections are carried out by teams of two structural engineers, who may be assisted 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 Fig. 1.

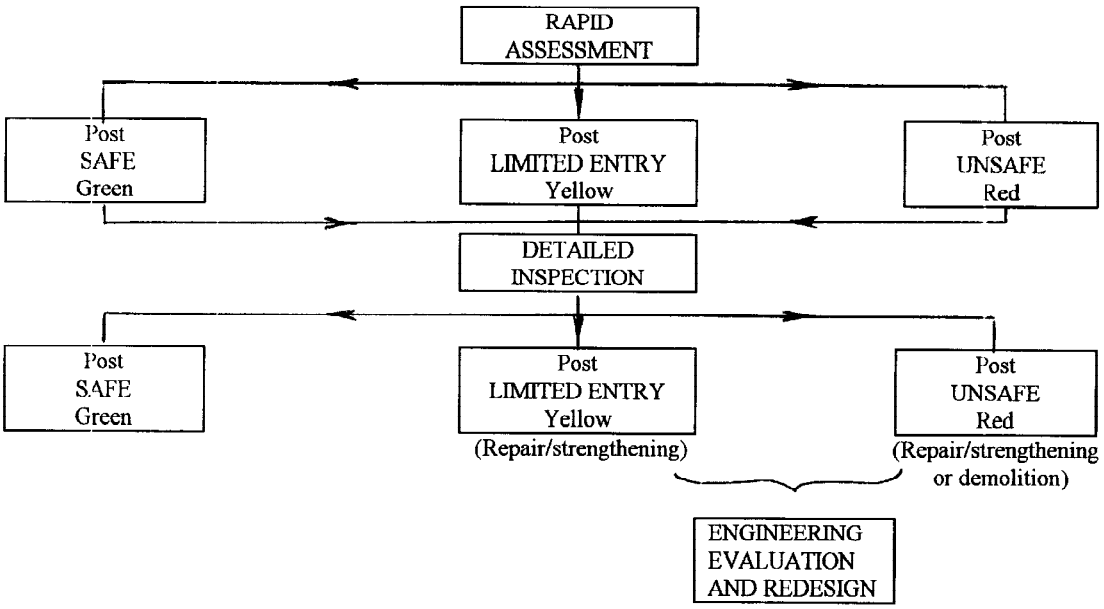

Fig. 1. Procedure for emergency assessment of building safety after a damaging earthquake

A rapid assessment is based on a visual examination of the building's exterior (only from the easily accessible sides) and of the ground floor, should not take more than about 30 minutes per building to complete and will result in the posting of each 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.

A detailed evaluation 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 evaluations from the beginning. The detailed evaluation is based on visual examination of the building's exterior as well as interior, including all its floors, basements and roof. It may involve plaster or movable panel removal to identify damage in structural members and could take anywhere between 1.0 to 3.0 hours to complete. **Obviously unsafe buildings must not be entered** and should be posted UNSAFE.

The inspectors will be filling an appropriate Damage Inspection Form (Fig. 2) , 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. After the building has been inspected and the Damage Inspection Form filled, the appropriate posting placard, Figs. 3, 4, 5, is completed and 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

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 (such as in #36, right) ☐

20. FURTHER ACTION ☐
    1 = None 2 = Remove local hazard
    3 = Urgent support required
    4 = Both actions 2 and 3 5 = Urgent Demolition

COMMENTS:

BUILDING INFORMATION (Additional)

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

ADDITIONAL DAMAGE RECORDING

28. INFILL WALLS ☐
29. FLOORS AND ROOF ☐
30. STAIRS ☐
31. PARTITIONS AND GLAZING ☐
32. ELEVATORS ☐
33. HEATING/AC ☐
34. ELECTRICAL INSTALLATIONS ☐
35. PLUMBING ☐

36. GROUND PROBLEMS ☐
    1 = None 2 = Settlement 3 = Liquefaction
    4 = Slope movement 5 = Ground fissures
    6 = Rockfalls 7 = Other (Explain below)
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)

21. EXISTING ☐
22. CURRENT ☐

COMMENTS :

INSPECTOR' S NAME: .....
SIGNATURE: .....

Fig. 2. 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 centers, 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 - religion 63 = Sports
64 = Culture / entertainment (museums, theaters, 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)

Fig. 2 (Continued). Emergency Earthquake Damage Inspection Form

also be marked on the building next to the placard, using a spray of the same color 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.

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. The necessary work will be carried out by specialized 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 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.

ORGANIZATIONAL ASPECTS

A catastrophic earthquake will usually create chaotic conditions and disarray in the stricken city. Therefore, to carry out the Emergency Inspections successfully, it is imperative to have a workable operational plan that will spell out all the details of the operation. Such a plan must be carefully prepared in advance and should be tailored to the specific administrative conditions as well as to the general emergency response planning applicable to the stricken region. The operation should be supported by an appropriate computer system, which will process the data on the Damage Inspection Forms brought in by the inspection teams and will produce lists with requirements for further actions, summary reports, etc.

Based on experience from past earthquakes, the organizational structure shown in Fig. 6 has been proposed (Anagnostopoulos, 1995). Teams of inspectors, ideally two structural engineers per team, and crews for emergency interventions, 2-3 people per team, constitute the basic personnel for carrying out the operation. Operational efficiency requires a coordinator for every 10 - 15 inspection teams and a coordinator for the emergency intervention crews. The team of expert structural engineers will be called to give opinion on difficult cases of safety assessment and emergency intervention (shoring or demolition) and also on important buildings, critical facilities etc. Success of the operation will depend to a great extent on the knowledge and capabilities of the person who will be in charge of it (chief of operations). He 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 country, 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 mobilization plan and the bureaucratic machinery that will support the operation. The above should be considered by the emergency agency planners who prepare the general mobilization plan, in which the official who becomes chief of operations will be designated. The structural inspectors should be city or state employees and in case their numbers are insufficient, volunteers from the private sector could be commissioned in cooperation with their professional associations.

The operational plan must include a checklist of the necessary actions for setting up the operation, detailed descriptions of tasks and responsibilities of all key personnel involved, lists of personnel with their permanent (i.e. non-emergency) affiliations and means of contact, lists of required material items and equipment with identification of their sources, lists of items that must be secured and stored in advance, so that they are readily available when the emergency occurs, etc. After the plan has been applied following a catastrophic earthquake, its shortcomings should be identified and corrected for its next application.

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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 STOREY	☐ NO RESTRICTIONS
☐ EXTERIOR, GROUND STOREY AND (specify):	☐ PARTIAL USE . LOCAL HAZARDS MARKED
☐ DETAILED	

DO NOT REMOVE THIS PLACARD UNTIL AUTHORIZED BY LOCAL AUTHORITY

Fig. 3. 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 STOREY	☐ ENTRY FOR EMERGENCY PURPOSES ONLY
☐ EXTERIOR, GROUND STOREY AND (Specify):	☐ OTHER
☐ DETAILED	

DO NOT REMOVE THIS PLACARD UNTIL AUTHORIZED BY LOCAL AUTHORITY

Fig. 4. 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 seriouly damaged and is unsafe. Do not enter. Entry may result in death or injury.

TYPE OF INSPECTION

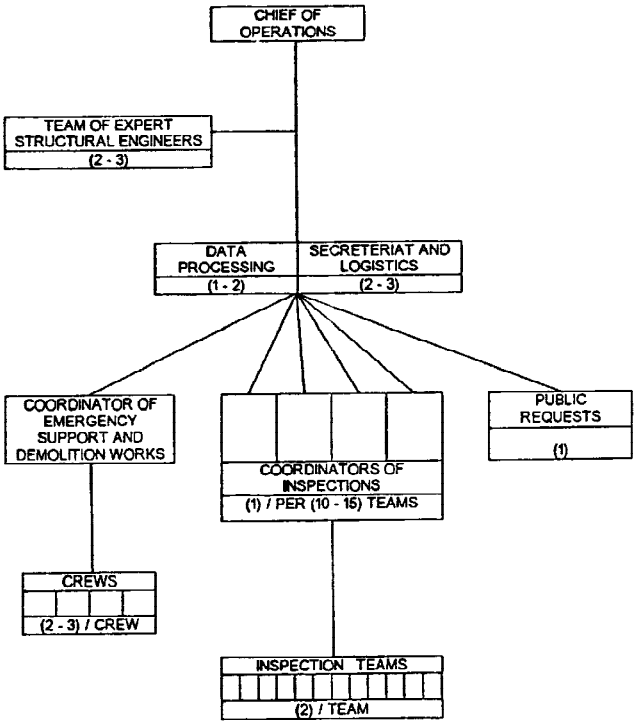
☐ EXTERIOR AND GROUND STOREY

☐ EXTERIOR GROUND STOREY AND:
(Specify) .....

☐ DETAILED

DO NOT REMOVE THIS PLACARD UNTIL AUTHORIZED BY LOCAL AUTHORITY

Fig. 5. Posting placard for UNSAFE buildings



Note: Indicative numbers of personnel shown in parentheses

Fig. 6. Organization for an emergency earthquake damage inspection operation