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Urban Search and Rescue and Rapid Field Assessment of Damaged and Collapsed Building Structures

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Abstract**—**Urban Search and Rescue (USAR) is a functional capability that has been developed to allow the United Kingdom Fire and Rescue Service to deal with 'major incidents' primarily involving structural collapse. The nature of the work undertaken by USAR means that staying out of a damaged or collapsed building structure is not usually an option for search and rescue personnel. As a result there is always a risk that they themselves could become victims. For this paper, a systematic and investigative review using desk research was undertaken to explore the role which structural engineering can play in assisting search and rescue personnel to conduct structural assessments when in the field. The focus is on how search and rescue personnel can assess damaged and collapsed building structures, not just in terms of structural damage that may been countered, but also in relation to structural stability. Natural disasters, accidental emergencies, acts of terrorism and other extreme events can vary significantly in nature and ferocity, and can cause a wide variety of damage to building structures. It is not possible or, even realistic, to provide search and rescue personnel with definitive guidelines and procedures to assess damaged and collapsed building structures as there are too many variables to consider. However, understanding what implications damage may have upon the structural stability of a building structure will enable search and rescue personnel to better judge and quantify risk from a life-safety standpoint. It is intended that this will allow search and rescue personnel to make informed decisions and ensure every effort is made to mitigate risk, so that they themselves do not become victims.

Keywords**—**Damaged and collapsed building structures, life safety, quantifying risk, search and rescue personnel, structural assessments in the field.

I. Introduction

THE search for the injured and rescue of those trapped are the most important activities in the immediate aftermath of any disaster, accidental emergency or act of terrorism, and should therefore be dealt with absolute urgency. Staying out of a damaged or collapsed building structure is not usually an option for search and rescue personnel, such as Urban Search and Rescue (USAR) and similar emergency services, as the urgent nature of the work means it is often necessary to gain entry as soon as possible.

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Search and rescue personnel operate in difficult circumstances, under pressure and against time, often having to make difficult decisions which have life and death consequences. An example being the decision to enter a damaged building structure to search for the injured and rescue those trapped, as entering a damaged building structure is 'never risk free' and because of this search and rescue personnel, by nature, 'take higher risks' [1]. Although attempts will be made to mitigate any risk, by keeping time spent in damaged building structures to a minimum and with temporary support (e.g. shoring and bracing), there will always be a risk that search and rescue personnel could themselves become victims.

To understand what guidance is available to assist search and rescue personnel to assess the structural stability of damaged and collapsed building structures, it is necessary to investigate the material produced for search and rescue personnel, particularly those directly related to field operations, such as any field and training manuals. In addition, it is also necessary to investigate what literature is available to structural engineers on the subject of structural investigation, assessment and appraisal and if, and how, any of this information could be used to assist search and rescue personnel.

II. Emergency Response and Relief Operations

There is a wide variety of published literature available on the subject of humanitarian response. These publications have been produced by various governmental and non-governmental organizations (including charitable agencies), which provide an invaluable resource for the co-ordination and management of emergency relief operations following a natural disaster or conflict [2]-[5]. Each publication is highly informative and offers comprehensive guidance on a wide variety of socio-economic factors, which range from the characteristics of human behaviour to minimum requirements for food, water, health, and sanitation. The information within these publications is very useful as it gives emergency relief workers an insight into sensitive issues which need to be considered when working with people who have lost everything and outlines what can be done to help with the rebuilding process. However, from the perspective of search and rescue personnel, who are deployed in the immediate aftermath of a disaster, accidental emergency or act of terrorism, the information within these publications is of limited value. Although the information does help search and rescue personnel to understand the socio-economic factors associated with emergency response and relief operations, particularly human behaviour, no information is provided about the search for the injured and rescue of those who are trapped.

A number of field manuals have been produced in recent years to provide search and rescue personnel with concise and easy-to-use reference documents to be used during operations. These field manuals have been produced specifically for Urban Search and Rescue in the United Kingdom (USAR) [6] and Urban Search & Rescue in the United States (US&R) [7]-[9]. Each manual contains essential operational procedures and guidelines for locating and extricating injured and trapped victims in damaged and collapsed building structures, in addition to other information which typically includes: organizational structure, assessment and management techniques, as well as roles and responsibilities.

It is a reasonable assumption that field manuals would contain significantly more information about search and rescue activities compared to the various texts that have been produced about humanitarian response. However, even within these field manuals there appears to be an obvious lack of technical information relating to structural stability, and the assessment of damaged and collapsed building structures. Rather than providing valuable guidance for structural assessment, such as hints to identify the structural systems in different types of building structures and examples of commonly associated structural defects, the field manuals only outline general sequences of procedures and safety considerations. It can only be assumed that the reason for this is that it is not practical for the field manuals to contain every aspect of search and rescue as the purpose of a field manual is to provide a clear, concise and easy-to-use reference document which can be used during operations.

III. Training

In the United States the Federal Emergency Management Agency (FEMA) is responsible for the deployment of US&R to a wide variety of accidental emergencies, natural disasters, and acts of terrorism. The multi-disciplined and demanding nature of work undertaken by US&R means that each member of the team must undertake hundreds of hours of extensive training in order to provide the necessary search, rescue, and technical capabilities required to work in an emergency situation. In order to achieve this, FEMA have developed a specialist in-house training programme comprising of a 'Structural Collapse Technician Course' (amongst others). The syllabus of the 'Structural Collapse Technician Course' covers a number of key modules for study, these include: structural engineering systems, shoring and bracing, breaching and breaking, and lifting and moving.

The *Structural Collapse Technician Manual* has been produced as a companion document to the 'Structural Collapse Technician Course' [10]. This is a very comprehensive manual that covers all modules within the 'Structural Collapse Technician Course' with information, that is not only relevant to students who are training, but can also be used as an ongoing source of reference. Basic principles of structural mechanics are outlined in a clear and concise manner throughout the manual, as well as how knowledge of these principles can be used to help better understand damaged building structures. The section of the manual about structural engineering systems is of particular interest as this contains information which would be very useful for search and rescue when assessing a damaged building structure. A summary of the format and content of the section about structural engineering systems from the manual can be seen as follows.

A. Building Materials and Structural Systems (Part 1)

1) Types of forces, properties and behaviour of the most commonly used building materials (concrete, steel, masonry, and timber) under normal loading conditions.
2) The function of primary structural systems and how these contribute to the overall stability and robustness of a structure.

B. Collapse Patterns (Part 2)

1) Types of forces that act upon a structure under extreme circumstances, such as: earthquakes, floods, wind storms, fire, and vehicular impact loading conditions.
2) Classification of different types of building structure with examples of commonly associated structural defects which can lead to failure.
3) Basic collapse patterns to demonstrate the general effects of the collapse of different types of building structure. This provides the required background knowledge for assessing how stable a structure is in its damaged condition and to identify what additional collapse could occur.

C. Identification and Building Monitoring (Part 3)

1) General guidance to identify hazards and safety concerns, detailing what to look for with different types of building structures.
2) Procedures for hazard mitigation when entering into partially collapsed and collapsed building structures.
3) The use of visual indicators to monitor damaged structures to act as a warning system of any change in stability.

D. US&R Strategy and Structural Size-Up (Part 4)

1) Outlines involvement at a disaster site, from arrival and the gathering of information from first responders to procedures for gaining access to injured and trapped victims.
2) The importance of having a strategy that considers all relevant structural hazards to minimize risk to injured and trapped victims as well as US&R personnel.
3) Use of 'structural triage' as a means of prioritizing search and rescue operations.
4) The structural condition of building structures are assessed to evaluate what resources are required to gain access and if search and rescue operations could proceed with or without stabilization works.

The format and content of the manual indicates that the ability to understand and apply the basic principles of structural mechanics to a damaged building structure requires knowledge of many interlinked factors. This is supported by FEMA who emphasizes with the importance of providing a suitable education base for search and rescue personnel, not only to enable the structural assessment of damaged and collapsed building structures to be carried out, but also to recognize where it is necessary to obtain professional advice from a structural engineer [11]. Although, a serious concern in the UK however, is that structural engineers rarely have suitable knowledge or experience of dealing with damaged and collapsed building structures and fewer understand the work that USAR does [12], [13].

A notable feature of the *Structural Collapse Technician Manual* is the use of diagrams as visual aids throughout the manual to demonstrate and reinforce the different points which are being made and how these can be applied in practice [10]. An example of the type of diagrams that are included within the manual is displayed in Fig. 1, illustrating typical construction details and safety concerns for the different types of building structures.

IV. Structural Investigation, Assessment, and Appraisal

There is a vast amount of published literature available on the subject of structural investigation, assessment and appraisal of building structures. Despite the availability of such literature, there is a distinct lack of material that is suitable and applicable for use by search and rescue personnel, to assess the structural stability of damaged and collapsed building structures. The reason for this being that the published literature available has been produced for structural engineers and other such professionals, to assess the general condition of a building structure under normal circumstances e.g. its ability to meet specific functional and durability requirements.

In IStructE publication, *The Structural Engineer's Response to Bomb Damage*, it is stated that most structural engineers have experience of assessing the condition of building structures under normal circumstances, but many would be unfamiliar with how to assess a building structure where damage has been caused by explosion [14]. Although this report focuses on explosion, damage caused by a range of disasters, accidental emergencies, or acts of terrorism would also add new dimensions which must be considered during the assessment process –as discussed in a FEMA publication, *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings: Basic Procedures Manual* [15]. When considering the fact that search and rescue personnel are not structural engineers and will be operating in difficult circumstances, under pressure, and against time, this emphasises the challenges which are being faced when assessing the structural stability of damaged and collapsed building structures.

In both IStructE and FEMA publications there is a similar view, that a competent structural engineer could, at least partially, assess the condition of a damaged building structure through the adaptation of assessment techniques by means of a knowledge about structural mechanics and understanding of building structures. Although these reports are discussing the ability of structural engineers to assess the condition of damaged building structures outside of normal circumstances, it suggests that the published literature about structural investigation, assessment, and appraisal could potentially be adapted to assist search and rescue personnel. However, this would require a suitable education base to be provided in order to give search and rescue personnel a basic knowledge about structural mechanics and understanding of building structures so that this could be applied a damaged building structure in the field [10]-[16].

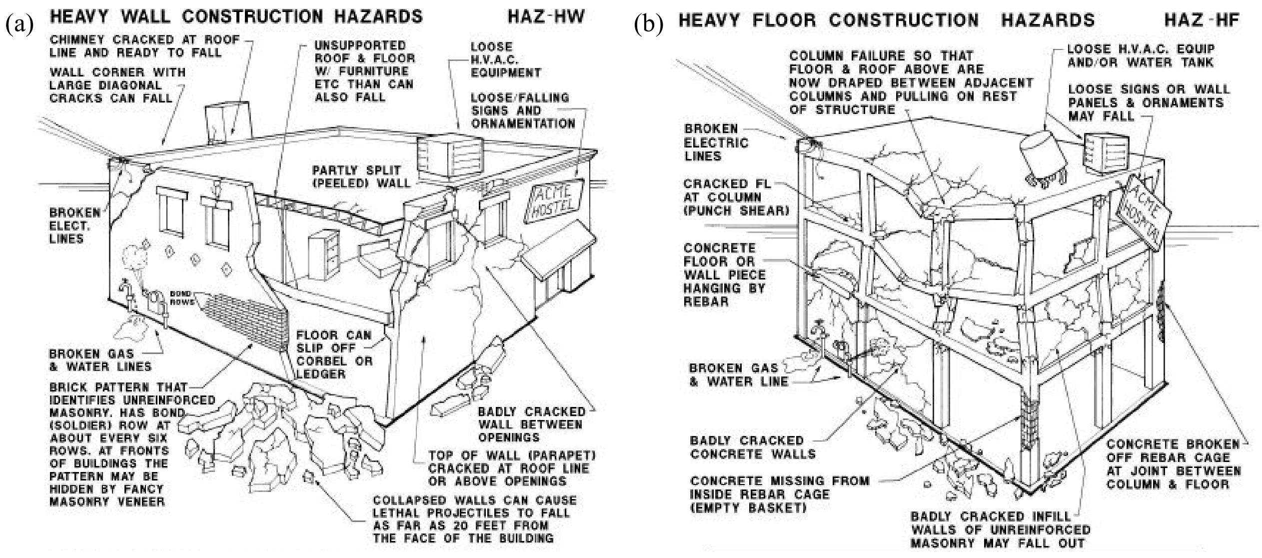

Fig. 1 Example of diagrams contained within the *Structural Collapse Technician Manual* (a) A typical masonry building structure [10] (b) A typical reinforced concrete frame building structure [10].

V. Techniques Used for Structural Assessment

A structural assessment or appraisal will usually be carried out on all types of structure, at some point during its service life, for many different reasons. The most common reasons for carrying out a structural assessment or appraisal are as follows:

1) Evidence of deterioration, structural weakness, or distress.
2) Part of a routine maintenance programme.
3) Accidental damage e.g. fire or impact.
4) Change of use or structural alterations.
5) Suspected defect in design or construction.
6) Legal purposes e.g. change of ownership or insurance.

Irrespective of the underlying reason for a structural assessment or appraisal, some form of inspection or survey will be required. The purpose of any inspection or survey is to gather as much information as possible from a structure that is readily available; this is to allow for an accurate structural assessment or appraisal to be carried out. A highly effective method of gathering information is a visual inspection, which is the most widely used technique and is often regarded as one of, if not the most, valuable part of any inspection or survey programme [17]-[22].

A visual inspection, sometimes known as a walk-over survey, involves the systematic examination of a structure to identify the location, nature, and extent of any damage, deterioration, or distress. It is advised that a staged approach should be adopted for the visual inspection of a building structure or other structure, which has been unoccupied for many years or has been damaged [23]. At first, a careful external reconnaissance should be carried out from a safe distance to determine whether it is safe to approach the structure, followed by a closer external examination. If visual inspections of the exterior of the structure indicate that it is stable, the structure can then be entered with caution. It is suggested that the structural stability of a building structure can be established simply by checking the alignment of structural elements e.g. the verticality of columns and walls, and the horizontality of beams and floors [23]. Although simple checks like this would be ideal for assisting search and rescue personnel to assess the condition of a damaged building structure, suitable guidance would still be required to help quantify risk.

To ensure that a visual inspection is successful, it is important that it is carried out systematically by trained and experienced personnel who are capable of making careful observations and recording findings accurately. Attention should be paid not only to areas with evidence of damage, deterioration, or distress but also to areas which are visually sound for comparison. A visual inspection normally forms the basis for the rest of the inspection or survey, as any observations and recorded findings often allows for a preliminary diagnosis to be developed. Based on this information a more detailed inspection can be planned, if required, which may include on-site testing, non-destructive testing and selected sampling to further assess the condition of the structure. It is therefore critical that an open-minded approach is taken to the visual inspection to ensure that any judgement made is based on observations and recorded findings rather than preconceptions.

In an IStructE report, it explains that when inspecting structures it is virtually impossible for a structural engineer, no matter how competent, to cover everything that could possibly be checked [24]. Although it is possible to suggest broad guidelines for inspecting structures, every inspection is different because every structure is unique and because of this, the use of survey forms is recommended. There are many practical advantages for using survey forms during inspections as these can help speed-up the inspection process and helps to ensure all relevant information is recorded. Fig. 2 shows an example of a survey form which has been developed to record the results of a visual survey for a concrete structure [17]. In this instance the survey form has a simple format and acts like a checklist by listing typical defects which are associated with the deterioration of concrete which includes a basic rating system and a section for addition comments.

Time spent pre-planning a visual inspection, or any other form of inspection or survey, is always recommended [17], [19], [21]-[24]. Pre-planning generally involves obtaining and studying existing records relating to a structure, such as: drawings, calculations and other construction details. This is a useful exercise as it allows structural systems and the location of structurally relevant components of the structure to be identified which, in theory, should allow more information to be recorded when on-site. Search and rescue personnel do not have the luxury of being able to obtain and study any existing records, what typically is available is basic information from first response emergency services and possibly people with a knowledge of a building structure e.g. locals, and occupants. It is therefore critical that search and rescue personnel are able to gain the maximum amount of information possible during a visual inspection and have a suitable education base to make judgements based on observations.

VI. Damage Assessment Systems and Techniques

The importance of using quick damage assessment methods in the post-disaster period has been identified as being an integral part of the overall disaster emergency relief plan [25]. It is recognised that in the short-term (days, weeks) quick damage assessment is very important from both an emergency and life-safety standpoint. Not only does a quick damage assessment prove to be an invaluable tool for search and rescue activities but it can also be used to prohibit entry into and the uncontrolled reuse of severely damaged and hazardous building structures – it is anticipated this would prevent additional injuries and loss of life caused by further collapse.

An interesting point that has been made is that the majority of publications concerning damage assessment methods after large scale disasters focus upon post-earthquake relief [25]. The reason for this is that earthquakes are one of nature's greatest hazards which are responsible for massive levels of destruction and thousands of deaths each year –it is estimated that 17,000 people were killed globally as a result of earthquakes each year during the twentieth century [26].

Structure .... Part of structure .... Date of inspection	Rating					
	0 None	1 Very slight	2 Slight	3 Moderate	4 Severe	5 Very severe
Defects						
Cracking	☐	☐	☐	☐	☐	☐
Plastic shrinkage/settlement	☐	☐	☐	☐	☐	☐
Thermal contraction	☐	☐	☐	☐	☐	☐
Structural	☐	☐	☐	☐	☐	☐
Crazing	☐	☐	☐	☐	☐	☐
Rust staining	☐	☐	☐	☐	☐	☐
Water leakage	☐	☐	☐	☐	☐	☐
Pop-outs	☐	☐	☐	☐	☐	☐
Spalling	☐	☐	☐	☐	☐	☐
Loss of surface	☐	☐	☐	☐	☐	☐
Abrasion	☐	☐	☐	☐	☐	☐
Chemical attack	☐	☐	☐	☐	☐	☐
Efflorescence	☐	☐	☐	☐	☐	☐
Others (specify below)	☐	☐	☐	☐	☐	☐
Existing repairs (if any)						
Delamination/debonding	☐	☐	☐	☐	☐	☐
Cracking	☐	☐	☐	☐	☐	☐
Others (specify below)	☐	☐	☐	☐	☐	☐
Supplementary documentation	**Details** (including reference numbers etc)					
Sketches	....					
Photographs	....					
Others (specify below)	....					
Additional comments (general condition of structure, local effects that may influence performance, such as damp areas).						

Fig. 2 Example of survey form used for visual inspections as part of a typical structural assessment and appraisal [17].

Many countries around the world are situated in seismically active regions, including the United States and Japan, who often have to deal with earthquakes. The destructive effects of earthquakes are often widespread and can vary significantly, from ground shaking and liquefaction causing building structures and other types of structures to collapse, to even causing landslides and tsunamis which can completely destroy all existing infrastructure. Damage assessment methods for post-earthquake relief must therefore be diverse, meaning that in theory these methods could be used for all post-disaster relief following natural disasters, accidental emergencies, and acts of terrorism.

Guidelines and procedures have been produced for use under emergency conditions following an earthquake, to minimise the risks associated with entering damaged building structures [1]. These consider a state of suspended animation may exist after an earthquake; where some building structures may have collapsed and others may have become unstable which could collapse at anytime, see Fig. 3.

Fig. 3 Example of damage witnessed after the 1995 Kobe, Japan earthquake (a) An unstable building structure [1]. (b) An unstable building structure which collapsed less than 24 hours after the original earthquake [1]

It has been recognised that assessing the structural stability of a damaged building structure may be a difficult task and is best judged by an engineer; however a level of acceptable risk must be established in relation to the urgency of the need to enter [1]. It is therefore advised that the decision to permit entry into any damaged building structure must not only consider the level of initial damage but also the possibility of aftershocks which could further aggravate existing damage.

Although the focus of most guidelines and procedures relates to earthquakes, these are also applicable to the period which follows any other form of disaster, accidental emergency, or act of terrorism. The effects of strong wind, additional explosions, collapse of nearby building structures, or even the activities of search and rescue personnel themselves, could potentially aggravate any existing damage. Similarly, further collapse may occur as a result of weakened structural elements. Search and rescue personnel must therefore understand the necessity to consider the possibility and effects of any addition damage when assessing damaged and collapsed building structures.

A. ATC-20

A definitive guide on the subject of damage assessment and classification of building structures following an earthquake is the ATC-20 publication series produced by the Applied Technology Council (ATC) [27]-[30]. These are often regarded as the 'best English publication(s)' as these contain practical guidelines and procedures for the assessment and classification of damage to the most common types of building structures found in the United States [1], [10], [25].

To promote consistent assessment, and classification, the safety evaluation strategy employs a three-tier structure, so that if independent assessments of damage to a particular building structure were to take place, these would all arrive at the same conclusion as to the posting classification for that particular building structure. A summary of the safety evaluation strategy is as follows:

1) Rapid Evaluation

The first level of the evaluation strategy is intended to be carried out quickly and with minimum manpower in about 10 to 20 minutes per building structure. Based on this evaluation it is possible to classify building structures as apparently safe (posted 'INSPECTED'), obviously unsafe (posted 'UNSAFE') and others where uncertainty exists, the so-called 'grey area structures' (posted 'RESTRICTED USE').

At this point the evaluation process involves a visual inspection of only the exterior of the building structure, unless there is a reported problem or the building structure cannot be adequately viewed from the outside. Obvious signs of structural distress are to be noted during the visual inspection include: partial collapse, leaning building structures, partial chimney collapse, and detrimental geotechnical conditions e.g. ground movement.

TABLE I
BASIC INSPECTION PROCEDURE FOR RAPID EVALUATION

Step	Task
1	Examine the entire outside of the structure.
2	Examine the ground in the general area of the structure.
3	Enter a building only when the structure cannot be viewed sufficiently from the outside. Do not enter obviously unsafe structures.

Inspection procedure taken from the ATC-20 Report [27].

TABLE II
BASIC INSPECTION PROCEDURE FOR DETAILED EVALUATION

Step	Task
1	Examine the entire outside of the structure.
2	Examine the site for geotechnical hazards.
3	Inspect structural systems from inside the building.
5	Inspect for non-structural hazards e.g. cladding, ceilings, partitions, etc.
6	Inspect for other hazards e.g. elevators, stairs, fire protection equipment, stored chemicals, etc.

Inspection procedure taken from the ATC-20 Report [27].

2) Detailed Evaluation

The second level of evaluation strategy is primarily used for the classification of building structures posted 'RESTRICTED USE' during the Rapid Evaluation. It is assumed that this evaluation will be carried out by at least two structural engineers, who have a good understanding of seismic design and experience of structural investigations, in about 1 to 4 hours.

The evaluation process involves thorough visual inspections of the entire building structure, both inside and out, where the primary focus is the structural system. Reasonable assurance is required that a building's structural systems are sufficiently safe to allow the building structure to be put back into service and reposted 'INSPECTED'. If any uncertainty exists as to whether the structural system is sufficiently safe then the posting classification will remain posted 'RESTRICTED USE'.

It is recognised that the Detailed Evaluation will require considerable use of judgement as it is expected that much of the structural systems will not be visible. At this point the use of destructive exploration is not recommended e.g. removal of plaster, studwork, or false ceilings.

3) Engineering Evaluation

This is the third and final level of the evaluation strategy and therefore the most thorough. It is used whenever a building structure has been damaged to such an extent that it is not possible to assess its safety with the use of visual inspection alone. After this level of evaluation, all building structures previously posted 'RESTRICTED USE' (during both the Rapid Evaluation and Detailed Evaluation) will be reposted as either 'INSPECTED' or 'UNSAFE'.

A structural engineering consultancy would take approximately 1 to 7 days (or more) per building structure and would produce detailed records of the damage, new structural calculations, and a quantitative assessment of the strength of the damaged structure.

Despite the ATC-20 series offering practical guidelines and procedures for the assessment and classification of damaged building structures, as well as an effective safety evaluation strategy, it is advised that these not be used by search and rescue personnel [25]. A reason for this is that the ATC-20 series has been developed so that the guidelines, procedures, and safety evaluation strategy are for use of structural engineers and other such professionals with at least 5 years of experience in general structural design, construction, or inspection. Another reason being, that these have primarily been developed for the assessment and classification of building structures in order to prohibit entry and to prevent the uncontrolled reuse of into severely damaged and hazardous building structures in regards to occupancy. The terms 'safe' and 'unsafe' are very different when used in the context of assessing a damaged building structure for search and rescue to when used for occupancy [1], [10], [25].

Although the ATC-20 series has been developed for use by structural engineers and other such professionals, it is an excellent example of how visual inspection can be tailored for the specific purpose of assessing damaged building structures. The fact that visual inspection is used within the three-tier structure of the safety evaluation strategy confirms that it is a very valuable tool which can be adapted and applied to assess the condition of damaged building structures following all types of disasters. Two different practical survey forms have been developed specifically for the assessment of damaged building structures following an earthquake, for use during the Rapid Evaluation and Detailed Evaluation stages of the safety evaluation strategy, as shown in Figs. 5 & 6. In addition to the survey forms, the pocket-sized *Field Manual: Procedures for Post-Earthquake Safety Evaluation of Building*, has also been produced to summarise important guidelines, procedures, and technical information to assist with the assessment and classification of damaged building structures [30].

ATC-20 Rapid Evaluation Safety Assessment Form

Inspection
Inspector ID: ______ Inspection date and time: ______ ☐AM ☐PM
Affiliation: ______ Areas inspected: ☐ Exterior only ☐ Exterior and interior

Building Description
Building name: ______
Address: ______
Building contact/phone: ______
Number of stories above ground: ____ below ground: ____
Approx. "Footprint area" (square feet): ______
Number of residential units: ______
Number of residential units not habitable: ______

Type of Construction: ☐ Wood frame ☐ Steel frame ☐ Tilt-up concrete ☐ Concrete frame ☐ Concrete shear wall ☐ Unreinforced masonry ☐ Reinforced masonry ☐ Other: ______

Primary Occupancy: ☐ Dwelling ☐ Other residential ☐ Public assembly ☐ Emergency services ☐ Commercial ☐ Offices ☐ Industrial ☐ Other: ______ ☐ Government ☐ Historic ☐ School

Evaluation
Investigate the building for the conditions below and check the appropriate column.

Observed Conditions:	Minor/None	Moderate	Severe
Collapse, partial collapse, or building off foundation	☐	☐	☐
Building or story leaning	☐	☐	☐
Racking damage to walls, other structural damage	☐	☐	☐
Chimney, parapet, or other falling hazard	☐	☐	☐
Ground slope movement or cracking	☐	☐	☐
Other (specify) ______	☐	☐	☐

Estimated Building Damage (excluding contents): ☐ None ☐ 0–1% ☐ 1–10% ☐ 10–30% ☐ 30–60% ☐ 60–100% ☐ 100%

Comments: ______

Posting
Choose a posting based on the evaluation and team judgment. *Severe* conditions endangering the overall building are grounds for an Unsafe posting. Localized *Severe* and overall *Moderate* conditions may allow a Restricted Use posting. Post INSPECTED placard at main entrance. Post RESTRICTED USE and UNSAFE placards at all entrances.
☐ **INSPECTED** (Green placard) ☐ **RESTRICTED USE** (Yellow placard) ☐ **UNSAFE** (Red placard)
Record any use and entry restrictions exactly as written on placard: ______

Further Actions Check the boxes below only if further actions are needed.
☐ Barricades needed in the following areas: ______
☐ Detailed Evaluation recommended: ☐ Structural ☐ Geotechnical ☐ Other: ______
☐ Other recommendations: ______
Comments: ______

Fig. 4 Example of the survey form used during the Rapid Evaluation Safety Assessment [28]

Another excellent feature of the publication series as a whole is the inclusion of *Case Studies in Rapid Post-Earthquake Safety Evaluation of Buildings*, which has been produced to demonstrate how to inspect and evaluate building structures for safety [30]. Each case study includes photographs to display the extent of the damage and also specific examples of how to fill in the survey forms correctly and what extent of damage would correspond to each posting classification e.g. 'INSPECTED', 'UNSAFE', or 'RESTRICTED USE'.

ATC-20 Detailed Evaluation Safety Assessment Form

Inspection
Inspector ID: ______
Affiliation: ______
Inspection date and time: ______ ☐AM ☐PM

Final Posting from page 2: ☐ Inspected ☐ Restricted Use ☐ Unsafe

Building Description
Building name: ______
Address: ______
Building contact/phone: ______
Number of stories above ground: ____ below ground: ____
Approx. "Footprint area" (square feet): ______
Number of residential units: ______
Number of residential units not habitable: ______

Type of Construction: ☐ Wood frame ☐ Steel frame ☐ Tilt-up concrete ☐ Concrete frame ☐ Concrete shear wall ☐ Unreinforced masonry ☐ Reinforced masonry ☐ Other: ______

Primary Occupancy: ☐ Dwelling ☐ Other residential ☐ Public assembly ☐ Emergency services ☐ Commercial ☐ Offices ☐ Industrial ☐ Other: ______ ☐ Government ☐ Historic ☐ School

Evaluation
Investigate the building for the conditions below and check the appropriate column. There is room on the second page for a sketch.

	Minor/None	Moderate	Severe	Comments
Overall hazards:				
Collapse or partial collapse	☐	☐	☐	______
Building or story leaning	☐	☐	☐	______
Other ______	☐	☐	☐	______
Structural hazards:				
Foundations	☐	☐	☐	______
Roofs, floors (vertical loads)	☐	☐	☐	______
Columns, pilasters, corbels	☐	☐	☐	______
Diaphragms, horizontal bracing	☐	☐	☐	______
Walls, vertical bracing	☐	☐	☐	______
Precast connections	☐	☐	☐	______
Other ______	☐	☐	☐	______
Nonstructural hazards:				
Parapets, ornamentation	☐	☐	☐	______
Cladding, glazing	☐	☐	☐	______
Ceilings, light fixtures	☐	☐	☐	______
Interior walls, partitions	☐	☐	☐	______
Elevators	☐	☐	☐	______
Stairs, exits	☐	☐	☐	______
Electric, gas	☐	☐	☐	______
Other ______	☐	☐	☐	______
Geotechnical hazards:				
Slope failure, debris	☐	☐	☐	______
Ground movement, fissures	☐	☐	☐	______
Other ______	☐	☐	☐	______

General Comments: ______

Fig. 5 Example of the survey form used during second stage, Rapid Evaluation Safety Assessment, of the ATC's three-tier safety evaluation strategy [28]

B. Documented Damage of Building Structures

A notable feature of the ATC-20 series is the frequent use of diagrams and photographs as visual aids to emphasise guidelines and procedures, and to illustrate what to look for during visual inspections. Throughout the ATC-20 series it states that a considerable amount of judgment is required to assess damaged building structures and it is very difficult, if not impossible, to develop damage evaluation procedures and guidelines that can be used without judgment. To help those undertaking the tasks of assessing and classifying damage to building structures following an earthquake, photographs have been included throughout the ATC-20 series to document the different types and varying extent of damage, see Figs. 6-9.

The main advantage of studying detailed analysis and photographs of different types of damage to and collapse of building structures which has occurred in the past, is so that valuable lessons can be learnt for the future, mainly to aid the design and construction of resilient building structures [31].

Fig. 6 Example of a crack pattern in the side wall of a masonry building documented in the ATC-20 series [29]

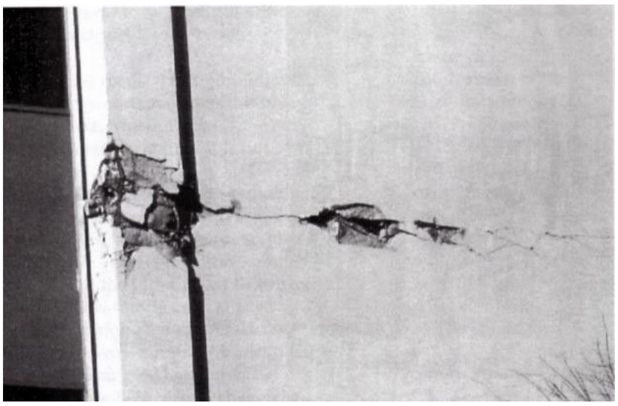

Fig. 7 Example of damage to a reinforced concrete shear wall along a horizontal construction joint documented in the ATC-20 series [29]

Fig. 8 Example of cracking of a precast concrete support of a parking structure documented in the ATC-20 series [29]

Fig. 9 Example of failed concrete piers (x-cracks) of a multi-storey building documented in the ATC-20 series [29]

The ATC-20 series has used photographs throughout to great effect in order to demonstrate the different types and varying degrees of damage which can be caused by earthquakes. The reason for this is not to learn lessons for future design or construction but to assist those undertaking the tasks of assessing and classifying damage to building structures to make accurate judgements and to promote consistency.

There are a number of publications and reports that are available which provide information about damage to building structures, one such example being the field reports produced by the Earthquake Engineering Field Investigation Team (EEFIT). These are a group of British earthquake engineers, architects, and academics who conduct field investigations following major earthquakes around the world. The primary purpose of the EEFIT field investigations is to assess current design practices and regulations by collecting detailed technical evaluations of the performance of structures, foundations and civil engineering works and to analyse the behaviour of structures when subjected to seismic loading. These field reports include nearly all of the major earthquakes which have occurred in the past ten years, such as: 2004 Indian Ocean Tsunami [32], 2008 China Earthquake [33], 2010 Haiti Earthquake [34], 2010 Chile Earthquake [35], and most recently, 2011 Japanese Earthquake and Tsunami [36]. Similarly, numerous other reports and publications have also been produced which document damage to building structures caused by earthquakes, particularly on the 2011 New Zealand Earthquake in Christchurch [37]-[40].

The ATC-20 publication series is an excellent example of a publication series that contain a range of important guidelines, procedures, technical information and visual aids, both diagrams and photographs, to assist with the assessment and classification of damaged building structures [27]-[30]. In particular, the *Case Studies in Rapid Post-Earthquake Safety Evaluation of Building* publication has been produced to demonstrate how to inspect and evaluate building structures for safety [29].

Fig. 10 Examples of damaged and collapsed building structures documented in reports by EEFIT (a) Tsunami damage to a residential building in Kalutara, Sri Lanka [32] (b) Earthquake damage to a traditional residential building in San Gregario, Italy [41]. (c) Earthquake damage to a school building in Talcahuano, Chile [35]

Each case study includes photographs to display the extent of the damage and also specific examples of how to fill in the survey forms correctly and what extent of damage would correspond to each posting classification e.g. 'INSPECTED', 'UNSAFE' or 'RESTRICTED USE'. Although it is advised that the ATC-20 series not be used by search and rescue personnel, lessons should be learnt from it [25]. For example, similar information needs to be available to search and rescue personnel which demonstrates what to look for during visual inspections, by documenting damage and also explaining what implication this may have on structural stability. Based on this type of information search and rescue personnel will be better equipped to make more accurate and consistent judgements when assessing damaged building structures and help to better quantify risk.

VII. Summary and Overview

The fact that there is such little published literature available to assist search and rescue personnel to assess the condition of a damaged building structure, indicates that this is a subject that would greatly benefit from research in the forthcoming years. After reviewing the literature that is available to search and rescue personnel, in addition to general structural investigation techniques and damage assessment methods, the following observations have been made:

1) Field manuals produced for search and rescue personnel lack technical information and guidance which would help considerably when assessing the structural condition of damaged building structures.
2) Search and rescue personnel must be equipped with a suitable education base, including the basic principles of structural mechanics and knowledge of construction would ensure a better understanding of the different types of damaged and collapsed building structures.
3) It is very difficult task to determine as to what constitutes as 'safe' and 'unsafe' in the context of search and rescue – search and rescue personnel must be able to quantify risk.
4) The majority of literature available about structural investigations, assessment and appraisal are not suitable

for search and rescue personnel. Although the use of visual inspection could be highly effective and a valuable tool, which could be adapted to assist search and rescue personnel to assess damaged building structures if appropriate training and guidance were provided.

5) Diagrams and photographs are important visual aids which can be used to demonstrate what to look for during visual inspections, such as commonly associated structural and non-structural defects. The use of diagrams and photographs to display the different types and varying degrees of damage which can be caused to building structures will help search and rescue personnel to make more accurate and consistent judgements when assessing damaged building structures in regards to structural stability.

(a) (b) (c)

Fig. 11 Examples of damaged and collapsed building structures documented in reports by EEFIT and other publications (a) A collapsed office building in Oroshi, Japan [36]. (b) A partially-collapsed warehouse in Christchurch, New Zealand [39]. (c) Earthquake damage to an apartment block in L'Aquila, Italy [41]

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