A Proposed Method for Conducting Structural Assessment for Search & Rescue Operations

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Abstract

International Urban Search & Rescue (USAR) involves locating and extricating live people trapped in collapsed buildings overseas, for example after earthquakes (e.g. Nepal 2015, New Zealand 2011, Haiti 2010, etc). The Structural Engineer's primary role within a USAR team is to provide technical engineering advise on the least-dangerous method to access and extricate those victims, whilst managing significant risks such as further collapse. They are also capable of undertaking a wide range of related tasks within the USAR team.

This paper presents (1) a proposed overview of USAR Engineers' inputs and responsibilities at each phase of the international USAR response cycle (from preparedness, to operation, to post-mission), and (2) a proposed decision-model outlining the process that USAR Engineers can follow in order to provide engineering advice on the least-dangerous method to access and egress trapped victims. This decision-model is demonstrated on a partially-collapsed case-study building.

Guidelines by the UN's International Search and Rescue Advisory Group (INSARAG) currently provide only a very brief outline of the Engineer's responsibilities and required qualifications. The aim of this work is to expand on the notes in the INSARAG Guidelines to give international USAR teams guidance on the roles, responsibilities, and processes conducted by USAR Engineers, which are common across INSARAG teams around the world.

This project has incorporated international workshops, exercises on live collapsed buildings and expert elicitation of over thirty USAR Structural Engineers and other technical participants from more than 15 countries over two week-long workshops in Old Poggioreale, Sicily, a town abandoned since it was partially destroyed by the Belice Valley Earthquake of 1968.

The outcome of this work is to inform a Guidance Note to be used by USAR Engineers, as well as researchers looking to understand how knowledge of building collapse and casualty modelling can be applied to the practices of international USAR teams.

Keywords: USAR, Search and Rescue, Casualties, Decision-Model, Professional Guidance

1. Introduction

Structural Engineers within International Urban Search & Rescue teams provide vital functions. The USAR Engineer's first priority is life-safety of their team, and of the victims and the local people of the affected area. To achieve this, they must be capable of undertaking a wide range of related tasks.

There exists a number of excellent structural collapse behaviour and shoring guides ([1], [2]), but the INSARAG Guidelines [3] currently provide only a very brief and high-level outline of the USAR Engineer's responsibilities and required qualifications. However, the Engineer's roles, responsibilities and processes onsite vary across teams and countries. This has implications for ensuring common minimum standards around the world, and also for cooperation and handover between teams during a deployment.

Further guidance is therefore required to promote common engineering practices within INSARAG teams around the world.

2. Methodology: Expert Elicitation and Onsite Exercises

To understand the different roles and processes of USAR Engineers in teams from different countries, two one-week workshops were arranged by THW Germany and Italian Civil Protection, for a total of over thirty USAR Structural Engineers and other technical participants from over 15 countries (see acknowledgements section). These workshops were conducted in Old Poggioreale, Sicily, a town abandoned since it was partially destroyed by the Belice Valley Earthquake of 1968. Buildings were mainly two or three storeys, consisting of traditional stone-rubble masonry with poor inner-connections, with timber or vaulted-masonry floors. Buildings were extensively damaged, displaying seismic damage similar to that observed in more recent earthquakes such as the 2009 L'Aquila Earthquake [4] and 2016 Central Italy Earthquake [5].

This expert elicitation process confirmed that the roles and processes of USAR engineers was not well defined and differed between teams. The workshop participants therefore worked together to establish on-site decision flow-charts, and to outline the Engineer's many roles within the USAR team at all phases of the deployment cycle: from pre-disaster to post-mission., Consensus was reached through multiple iterations, tested through onsite exercises.

Onsite exercises consisted of various casualty scenarios on the seismically-damaged buildings of Old Poggioreale, Sicily. During these scenarios, the USAR Engineers would follow the defined decision flow-charts in order to provide technical engineering recommendations to the USAR Rescue Leaders on the least-dangerous way to access and extricate trapped victims. Workshops were then conducted to discuss feedback and suggestions on the proposed flow-charts based on the teams' experiences onsite.

This paper presents the resulting decision flow-charts and agreed roles at each stage of the deployment cycle, along with description of the agreed processes to be followed. The decision flow-charts are demonstrated on a case-study building at the end of this paper.

It is intended that these results will also be published as an INSARAG Technical Guidance Note [6], to support all USAR Engineers from teams classified under the INSARAG system.

3. Outcome 1: Offsite Roles and Responsibilities of the USAR Engineer

The USAR Engineer's first priority is life-safety of his or her team, and of the victims and the local people of the affected area, and the INSARAG Guidelines set out the basic general requirements and expectations. The expert elicitation process applied in this project highlighted the USAR Engineer's further roles and responsibilities at all phases of the International USAR Response Cycle, to best meet this life-safety objective. The phases are illustrated in Figure 1 below.

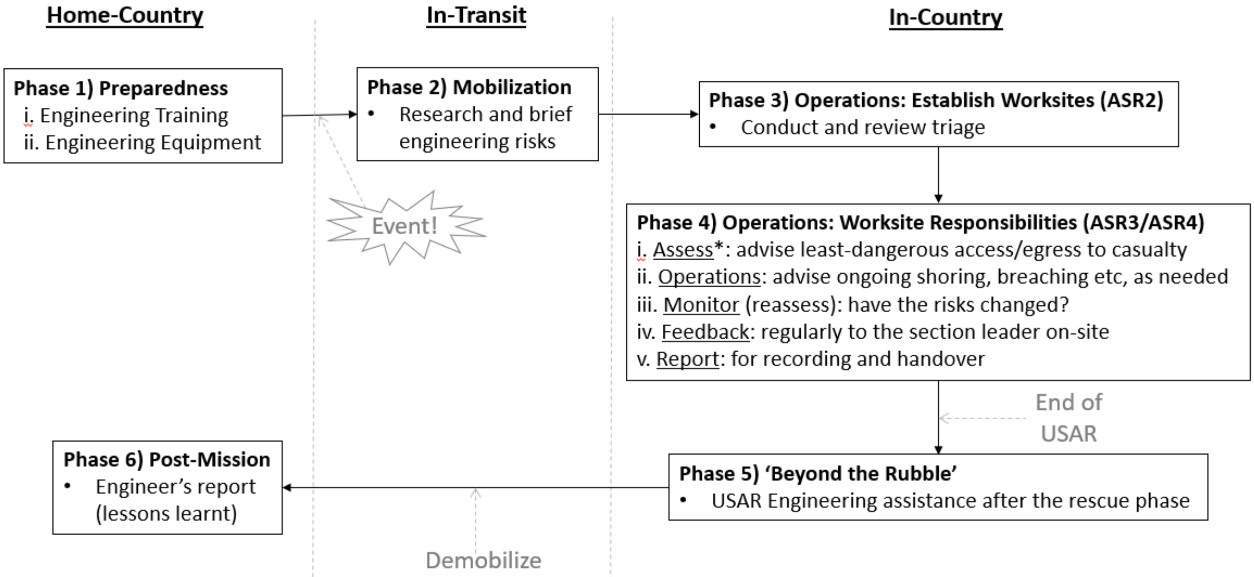

Figure 1: USAR Engineer Inputs and Responsibilities at each Phase of the International USAR Response Cycle. Phases are adapted from [7].

This section outlines the results of the expert elicitation process for the initial offsite phases (Phase 1 to Phase 3, Figure 1). Note that Phase 5 and Phase 6 ('Beyond the Rubble' and post-mission) are expanded on in the proposed Technical Guidance Note, but are omitted from this paper for brevity.

3.1. Phase 1 - Preparedness

USAR Engineering requires competencies which are outside of the experience of most engineers, and so requires specific training which goes beyond the current INSARAG guidance. These additional training requirements must cover two areas of competence: general Structural Engineering, and Rescue Engineering.

General Engineering training topics include: loading and effects due to typical hazards (e.g. seismic, tsunami, extreme wind, extreme snow, flooding, explosions, landslides and hazardous materials) and subsequent structural behaviour of typical structural systems (including non-engineered construction). Emphasis should also be placed on earthquake aftershock expectations, seismic sequences and epicentre migration, and structural behaviour under earthquake loading (including repeated loading and residual capacity).

USAR training topics include the INSARAG USAR methodology, emergency shoring, working in confined spaces, and common techniques for rescue personnel (e.g. rope rescue, safety considerations of emergency site, HAZWOPER-Hazardous Waste Operations and Emergency Response).

USAR Engineers must be familiar with the range of equipment and tools used by their USAR team, including monitoring equipment and the specific shoring equipment and capacity of the team. They must also be fully conversant in the use of technical equipment for which they may be asked to lead the team in using (e.g. GPS, laser-tapes, WASPs, Total Stations, etc).

3.2. Phase 2 - Mobilization

The Mobilization Phase occurs after it has been confirmed that a team will deploy following an overseas event, but before the team's arrival in-country. Examples of the Engineer's input during this phase include the research and briefing of the team on:

- The hazard: e.g. seismic intensity maps, hazards maps, historical earthquake maps, geography and terrain conditions, soil conditions (site amplification).
- Relevant typology information: e.g. structural material, load-resisting system, number of storeys, year of construction, as well as associated collapse types and potential shoring materials.
- Relevant building code information: e.g. current/past codes, seismic zonation (including design ground acceleration), and advice on whether the country has a high proportion of buildings which do not follow building codes (and the implications of this on likely failure patterns, and risks of further collapse).

3.3. Phase 3 - Operations: Establish Worksites

Examples of engineering input on arrival in-country include:

- Wide-area assessment: Interpret mapping, aerial photography and initial assessment information in order to provide focused engineering advice (e.g. identifying landslide or liquefaction risk areas relevant for base-of-operations location selection).
- Sector assessment: Conduct and review triage of damaged buildings in the affected area in order to establish viable worksites.

The INSARAG forms and paperwork [8] may be completed by others on the team, but engineering input is preferable for items relating to the structural type, structural damage and structural hazards. When providing recommendations to the rescue team it is important not to assume that the rescue team onsite will always have an engineer present, and so ensure that relevant engineering observations are included in the briefing and handover paperwork. Note that once specific worksite operations are underway the USAR Engineer's priority is life-safety on those worksites, and so undertaking triage of worksites becomes a secondary engineering responsibility.

4. Outcome 2: Onsite Processes for the USAR Engineer

This section outlines the results of the expert elicitation process for the USAR Engineer's responsibilities on an active worksite (i.e. where technical search or rescue operations are underway) in support of INSARAG rescue processes. This corresponds to Phase 4 of the response cycle defined in Figure 1.

4.1. Structural Assessment

The outcome focus of a Structural Assessment for rescue operations is to provide engineering advice on the least-dangerous way to access and extricate the victim. This advice must identify significant structural risks and propose the preferred method to manage those risks. That advice must then be explained concisely and clearly to the Operations Leader (or whichever terminology is used by the respective teams to indicate the person in charge of the worksite) to help them make operational USAR decisions.

The structural assessment should focus on the location of the victim(s) if known. It is however critical that the USAR Engineer begins with a comprehensive appreciation of the hazards present in the environment surrounding the worksite. Once these have been systematically assessed, the USAR Engineer can focus on the building or structure that is the worksite – firstly the exterior, and then the interior, provided the building is safe enough to enter.

The structural assessment should, therefore, be conducted in 3 stages (see Figure 2), with the key considerations and questions within each as follows:

1) **Assessment of Surroundings**
   - The focus is on the surroundings of the buildings.
   - Is it 'safe' to approach the building, or are there surrounding risks that must be managed? E.g. a neighbouring building that may collapse onto the worksite, or potential for landslide are surrounding risks.
   - Establish a suitable "Safe zone" for the rescue team outside the building (1.5 or 2 times the height of the building).

2) **External Assessment**
   - Are the services cut? Electricity, gas, water, etc.
   - Are there visible cracks, displacements, visible structural failures?
   - Can we identify the construction system, materials and failure pattern?
   - What are the viable/ least-dangerous entry/exit points to the building?
   - Is it 'safe' to enter the building, or are there external risks that must be managed? E.g. an unstable upper-storey wall, or an air-conditioning unit which may fall onto the entry point are external risks.

3) **Internal Assessment**
   - The focus is on the interior of the building.
   - Are there 'significant risks' (refer Figure 3) inside the building which must be managed before rescue workers can operate? E.g. any equipment or furniture inside a building which may fall onto the personnel.
   - Is the structural system the same as the outside? How has it changed? What are the new structural risks? E.g. refurbished buildings may have an retained masonry façade about an internal steel or RC structure.
   - Are there visible cracks, displacements, visible structural failures?
   - What is the additional imposed load from rescuers?
   - Are there any 'safe points' that rescuers can shelter in inside the building, in case of an aftershock.
   - Identify the emergency exit path.

Assess and manage risks (as necessary) before progressing to the next stage. Personnel, including the Engineer, should not enter the building if the external assessment indicates that it is unsafe to do so until risk management procedures are conducted.

For a structural assessment, the guiding principle is to follow the load paths. Consider whether the structure's ability to resist vertical and horizontal load has been reduced due to recent damage. Consider both the building (superstructure) and foundations (sub-structure). Consider the pre-incident state of the building, what has changed, and how it might move further in an after-shock or subsequent collapse.

To assess 'Significant Risks', follow the procedure in Figure 3. Once a risk has been identified by the Engineer as a 'Significant Risk', then a risk management method should be proposed (see the case-study in Section 5 for examples).

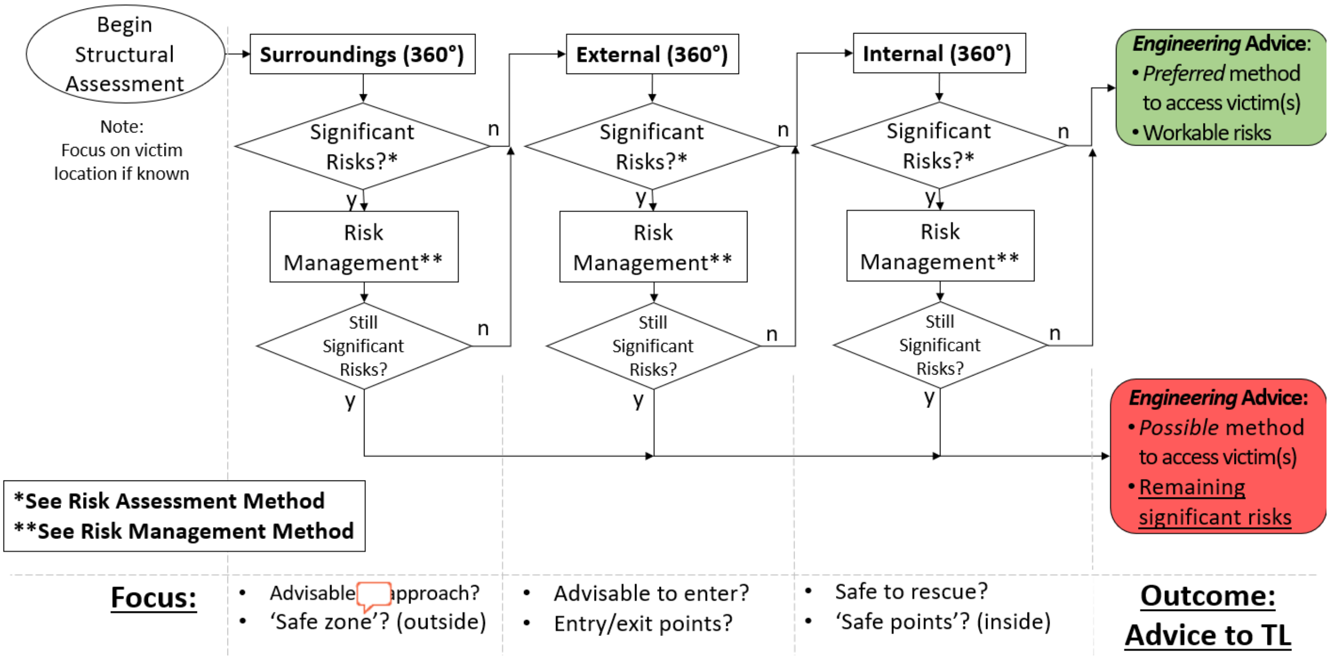

Figure 2: Structural Assessment Method

4.2. Risk Management Method – ARMM

To assess 'Significant Risks', follow the procedure in Figure 3. 'Significant Risks' are those where, if an aftershock (of similar intensity to the mainshock) occurred the structure would not be able to resist further damage:

- Demand = imposed load or deformation caused by the hazard
- Capacity = strength or allowable deformation of key elements about the rescue area
- If Demand > Capacity then the risk is considered a 'Significant Risk'

The above definition is a rough guide to help the Engineer make a judgement-based decision quickly. The overall significance of the risk will depend on operational considerations, which should be discussed with the Operations Leader, who will then have to make further operational considerations including the lives to be saved, and the time needed for the rescue.

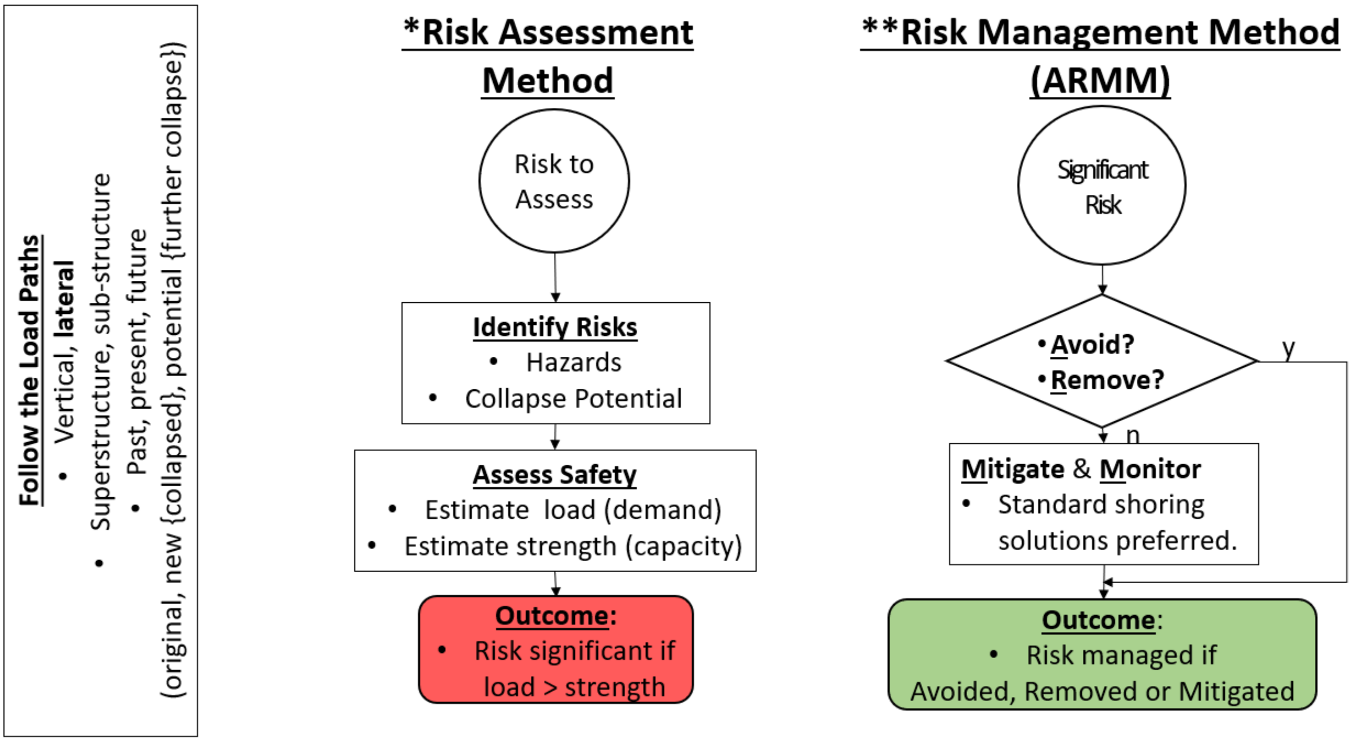

Figure 3: Risk Assessment and Management Method

The Risk Management Method in Figure 3 outlines the following options for managing risks:

- <u>A</u>void the risk (go a different way)
  - E.g. if an external assessment highlights a high-level unstable wall over an entry point, then perhaps it would be safer to propose an alternative entry point. This is avoiding the risk.
- <u>R</u>emove the risk (take the risky item away)
  - E.g. if an unstable wall is a risk, then perhaps it would be safer to tear the wall down before beginning the rescue. This is removing the risk.
  - Note: It is very important, before removing the risk, to make sure that the selected part to be removed, is not a structural member (or part of it) of the building, that will affect its stability.
- <u>M</u>itigate the risk (make the risk less risky)
  - E.g. shoring an unstable wall. This is mitigating the risk.
- <u>M</u>onitor the risk (check if anything changes)
  - E.g. monitor an unstable wall to warn the rescuers if anything moves (e.g. using a WASP, Sentry etc).

5. Case-Study

The Structural Assessment method of Figure 2 and Risk Assessment and Management Method of Figure 3 are demonstrated on the case-study building shown in Figure 4. Information relevant to the assessment of the building is shown in Table 1.

Figure 4: Case-study hotel building in Pisco, Peru

Table 1: Relevant information to the building's structural assessment.

Original Structure (Past)	**Current Structure (Present)**	**Collapse Potential (Future)**
Corner located. Hotel Building. 2-stories. Reinforced masonry walls with poor quality concrete frames. Extension of 3 stories and conversion to hotel and casino on the ground floor.	EQ occurred at 18:40 pm. Pancake collapse of the ground and first floors of the building. 15 Casualties confirmed in the ground floor.	See Surrounding, External and Internal risk assessments below.

Figure 5 and Figure 6 show significant risks observed from external and internal assessments, respectively. The significant risks, and proposed risk management methods are presented in Table 2. The overall recommendations to the Rescue Manager are also presented in Table 2.

Figure 5: **External Assessment**. Numbers correspond to hazards shown in the images and table.


Picture 1

Picture 2

Picture 3

Picture 4

Picture 5

Picture 6

Figure 6: **Internal Assessment**: The picture numbers correspond to the descriptions in **Error! Reference source not found.**.

Table 2: **Assessment Overview and Engineering Advice to Rescue Manager**. Risk numbers for the external and internal assessments correspond to the numbers shown in Figure 5 and Figure 6.

Method to Access Victim(s)	
Safe Zone (outside)	Street/square to west and south of the building.
Entry/exit points	Entry point through the rooftop (accessed from neighbouring building) or from any side with large openings are and where the significant risks have been managed. Accessing the ground-floor of the building would need a shoring system before proceeding.

Risks & Risk Management

Assessment	**Significant Risks**	**Proposed Risk Management Method (ARMM)**
Surroundings	From rapid visual external inspection, lateral load resisting systems of adjacent buildings appear damaged and further collapse or falling debris possible in aftershock. Also lighting poles in the street are loose and could fall.	**Avoid** by minimizing operation and transit near collapsible facades of significantly damaged neighbouring buildings and secondary structures. Either actively **Monitor** surrounding structures and loose elements (lighting poles) at risk of collapse, or if risk low then simply take photos from a fixed position, to compare with building position after any subsequent photos.
External	1. Further collapse and ‘sliding off’ of hanging rooftop	**Avoid** climbing on/disturbing collapsed/hanging floors, if an alternative route to victims can be found (e.g. approach voids between slabs from the side, without the need to climb on hanging slabs).
	2. A loose piece of beam	**Avoid** passing under that element and use an alternative route to access (e.g. the other side of the building). **Remove** if possible. **Mitigate** by using a temporal shoring solution.
	3. Fall-hazard of collapsed / hanging element	**Avoid** passing under the loose elements and use an alternative route to access. **Remove** by taking out the elements with an aerial truck. **Mitigate** by tying the elements to stable anchors.
	4. Small objects in the upper floors	**Mitigate** by going to the top and tying the objects. **Remove** by going up and moving the objects.
	5. Detached masonry walls.	**Avoid** working and passing next to the wall. **Mitigate** by installing a raker system. **Monitor** with any monitor device (e.g. WASP etc).
Internal	1. Column punch through the floor, structural configuration problems may be present.	**Avoid** walking in those areas where the floor may be loose weak to withstand weight
	2. Beam cracked and poor rebar seen.	**Avoid** working in areas where structural elements are potentially working under their capacity. **Mitigate** by using shoring systems under the other beam and the roof.
	3. Several cracks in non-structural walls	**Avoid** working next to that walls and if needed then **Mitigate** by shoring with a small raker solution. **Monitor** if cracks are seen in bearing walls.
	4. Loose elements from upper floors	**Avoid** working near the parts where no protection exists. **Mitigate** by going to the upper floors and tie back the elements or **Remove** the elements.
	5. Cracks of the wall that should be a column	**Mitigate** by using shoring systems in several places to create a safe haven to perform operations. **Monitor** inside and outside (e.g. using WASP etc).
	6. Loose elements from the rooftop	**Avoid** working near the parts where no protection exists. **Mitigate** by going to the rooftop and tie back the elements or **remove** the elements.

6. Conclusions

This paper has presented the outcome of international workshops, exercises on live collapsed buildings and expert elicitation of over thirty USAR Structural Engineers and other technical participants from more than 15 countries, to define:

(1) A proposed overview of USAR Engineers' inputs and responsibilities at each phase of the international USAR response cycle (from preparedness, to operation, to post-mission. See Figure 1), and

(2) A proposed decision-model (Figure 2 and Figure 3) outlining the onsite process that USAR Engineers can follow in order to provide engineering advice on the least-dangerous method to access and egress trapped victims.

During numerous onsite exercises the decision-model presented in this paper enabled USAR Engineers to come to agreement on the engineering recommendations to be made as to the least-dangerous way to access/egress trapped victims, despite different backgrounds and experiences from their respective countries. This paper has demonstrated the decision-model on a partially-collapsed case-study building (Section 5).

This work is aimed at international USAR teams and USAR Engineers, as well as researchers looking to understand how knowledge of building collapse and casualty modelling can be applied to the practices of international USAR teams.

The outcome of this study is to inform a USAR Engineering Guidance Note, to expand on existing guidance by the UN’s International Search And Rescue Advisory Group (INSARAG). The proposed Guidance Note is to give international USAR teams guidance on the roles, responsibilities, and processes conducted by USAR Engineers, which are common around the world.

7. Acknowledgements

This work is thanks to the organisers, partners and participants of the INSARAG Structural Engineer’s Course, in particular THW and Italian Civil Protection. Thanks also goes to Antonios Pomonis of the World Bank for his assistance on defining several case-study buildings. Special thanks also goes to the many international reviewers who provided feedback on this work. A full list of acknowledgments is provided with the INSARAG Structural Engineer’s Guidance Note.

8. References

[1] D. F. Merchant and D. Ashford-Smith, *USAR Operations*. 2016.

[2] *Urban Search & Rescue Structures Specialist FIELD OPERATIONS GUIDE*. U.S. Army Corps of Engineers Urban Search and Rescue Program, 2017.

[3] INSARAG, “INSARAG Guidelines, Volume II: Preparedness and Response, Manual A: Capacity Building,” 2015.

[4] EEFIT, “THE L’AQUILA , ITALY EARTHQUAKE OF 6 APRIL 2009: A PRELIMINARY FIELD REPORT BY EEFIT,” 2009.

[5] EEFIT, “A FIELD REPORT BY EEFIT: THE M W 6.2 AMATRICE , ITALY EARTHQUAKE OF 24 th AUGUST 2016,” 2016.

[6] J. Macabuag, D. Brunsdon, O. Lizarzaburu, P. Goxharaj, and M. Keogh, “INSARAG Structural Engineer’s Guidance Note.” 2020.

[7] INSARAG, “INSARAG Guidelines, Volume II: Preparedness and Response, Manual B.” 2015.

[8] INSARAG, “Worksite Triage Form.” 2015.