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SEARCH AND RESCUE IN COLLAPSED REINFORCED CONCRETE BUILDINGS

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SUMMARY

This paper reports on recent work on the subject of search and rescue in collapsed buildings following earthquakes. While modern reinforced concrete buildings may be expected to survive earthquakes without serious damage, the experience of recent earthquakes demonstrates that some such buildings are subject to catastrophic failure. Because these buildings may be large with high occupancy rates, they pose a special problem for search and rescue workers after an earthquake. The mass and strength of materials in collapsed reinforced concrete structures necessitates the development and utilization of specialized techniques and equipment for the location and extrication of entrapped victims.

INTRODUCTION

Urbanization around the world has resulted in the growth of many centers of dense population in recent years. Rapid urbanization has also resulted in the expanded use of modern building methods. In many countries of the world, including those in seismic zones, we have seen a dramatic increase in the number of medium and high rise reinforced concrete buildings. These buildings serve many purposes, residential, commercial and institutional. While well-engineered and constructed buildings should be expected to survive earthquakes without serious damage, recent earthquakes have resulted in the catastrophic failure of large modern buildings. In such large buildings, hundreds of lives have been lost immediately and hundreds more have been trapped or entombed in the rubble. These trapped victims are often seriously injured and in need of immediate medical assistance.

At present, throughout the world there are very limited resources of trained personnel or specialized equipment for search and rescue in building collapse. (Ref. 1) There are several organized national teams which specialize in international disaster response, but they are largely dependent on techniques and technologies developed for other types of rescue operations and not particularly effective in the reinforced concrete environment.

Research to Improve the Rescue Environment The problem of major building collapse has recently been recognized as a continuing and possibly a growing problem. It has also been recognized that little or no research effort has been dedicated to this rescue problem.

The rescue problem requires a multidisciplinary approach. It requires the collaboration of structural engineers familiar with the characteristics of building design and materials, architects and social scientists familiar with building use and occupant behavior, and emergency medical personnel familiar with the injury patterns associated with building collapse as well as injury epidemilogists familiar with the statistical distribution of morbidity and mortality related to variables such as building type and rescue methods. (Ref. 2)

The major areas in need of research are the following: 1) analysis of modes of collapse and identification of prototypes for rescue planning and training; 2) damage assessment to establish relationships between building damage, occupancy and estimates of entrapped victims, and also needs assessment for manpower and equipment; 3) search technology to develop a comprehensive rational process which incorporates currently available technologies as well as to develop performance requirements for new technology; 4) extrication technology to develop a comprehensive rational process which incorporates currently available technologies and also to develop performance criteria for new technology; 5) emergency medicine, to address the specific problems of crush syndrome, spinal column injury, asphyxiation and dehydration, and epidemiological studies of injury patterns related to building failure and survival rates related to rescue time and methods; 6) management of the search and rescue function to develop a unified strategy for attack of the single site and the allocation of resources for multi-site events, and analysis to improve the coordination and communications of multi-organizational response (especially multi-national response); 7) training for structural collapse search and rescue, including development and incorporation into appropriate professional responsibilities of process and materials, and development of means for public information to enhance and control volunteer response.

Recent Experience: In Mexico City, in September, 1985, earthquakes gained world-wide attention when over 400 buildings, many of which were large, modern, and of concrete "flat slab" or "waffle slab" construction, collapsed. An estimated 10,000 people were trapped in these buildings.

Spontaneous volunteer rescue efforts were able to remove people with light injuries at the surface of the debris, and this activity accounted for a large number of the rescued. However, the cases of more seriously entrapped or entombed people required specialist or professional rescue expertise.

Nine international rescue teams were sent to Mexico City. They came from France, Switzerland, the Federal Republic of Germany, Italy, the United Kingdom, Israel, Venezuela, Guatemala and the United States. These groups worked with the Mexican Army, the Mexican Red Cross, groups of Mexican mining engineers and volunteers. Each group brought its own set of equipment and procedures. As a result, Mexico City offered an international review of the state-of-the-art in search and rescue technology for building collapse. (Ref. 3)

Particularly illustrative of this experience in Mexico City was the rescue operation at the Juarez Hospital. (Ref. 4) The main tower of the hospital was built in 1970. It consisted of 12 floors distributed in two wings. On the day of the eqrthquake the hospital was 80% full. At the time of the earthquake, 7:19 AM, the nurses were changing shifts, and the halls were full of students and professors. The medical residents were preparing their daily rounds and the operating rooms were about to begin their first round of operations. At the time of the earthquake it is estimated that the hospital was occupied by 950 people.

Immediately following the collapse of the tower, doctors, nurses, students and hospital workers attempted to rescue those victims near the surface. The first rescue work was done by the personnel of the hospital aided by neighborhood volunteers.

Eventually, organized rescue groups arrived to coordinate the operation. The sapper corps of the Mexican Army arrived to assist in the removal of rubble.

At this time the number of seriously injured victims, some with amputations done by the rescuers, required the expansion of the first aid post.

When the rescue groups were fully occupied and making progress towards identification of victims, roughly 36 hours after the initial shock, a new tremor caused more movement and settling in the rubble. Following the second shock, contact was lost with some victims who had already been located. The rescue work became slower as large blocks of reinforced concrete impeded further penetration.

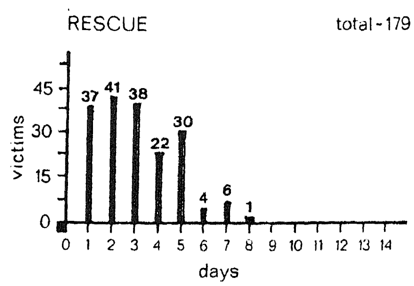

Figure 1

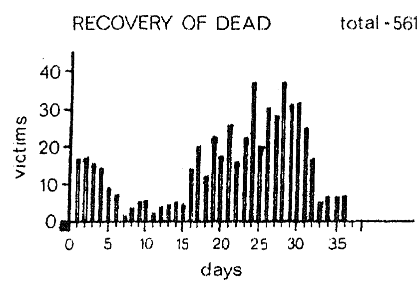

Figure 2

In evaluating the progress of the rescue operation (Figure 1) it is apparent that the rate of extrication reflects the arrival of the professional teams on the second day and the impact of the second tremor at the end of the second day. It is also important to note that by the fifth day many international rescue teams were active on the site and some heavy machinery was used to accelerate dismemberment of the building.

In evaluating the rate of recovery of the dead (Figure 2) it is important to note that the marked increase in recoveries on the 24th day was related to the uncovering of the stair and elevator towers where a great number of people had congregated at the time of collapse. Immediate entry to this area might have resulted in a higher rate of survival.

Data has also been collected on the major causes of injury. The distribution is as follows:

Penetration wounds	13.38%
Fractures	16.18%
Crush	3.52%
Amputation	8.45%
Contusion	35.31%
Dehydration	22.53%

It is important to note that while the bulk of the rescues (94%) were accomplished by the end of the fifth day, there were still living victims in the building until at least the eighth day.

The detailed relationship of victim recovery data and injury data with both the physical problems of location and extrication and the organizational structure of the rescue effort should yield further insight for improvement of rescue efforts.

Early Results of Research 1) Generalized phases of victim location and extrication are:

Day 1 - 2	Spontaneous (self and mutual rescue)
Day 1 - 5	Light professional (dog search/ hand tools)
Day 5 - 10	Heavy professional (technical search/special tools)
Day 10 - 20	Body recovery (heavy equipment)
Day 20 +	Demolition and debris removal

2) Most victims who survive are recovered in the first 48 hours after the earthquake.

3) Special conditions may allow some victims to survive up to 5 - 6 days.

4) The maximum survival period for entrapped victims without food or water is about 10 days (exceptional cases of 14 days are recorded.)

5) Most victims (80% - 90%) are rescued by self or non-professional volunteers.

6. Some victims die after extrication or are seriously injured as a result of improper methods of rescue.

7. Search techniques are inadequate for the environment of collapsed reinforced concrete structures.

8. Extrication techniques are inadequate for the environment of collapsed reinforced concrete structures.

9. Management of search and rescue efforts has been hampered by lack of clear structure of authority, lack of common strategy of attack, lack of compatible methods and technologies, and lack of an adequate communications net.

Work Which Remains to be Done: 1. Relevant data must be collected and analysed from all available past events. We must maximize learning from the past. Data should include: a) injury patterns related to building failure; b) survival rate related to injury type; c) survival rate related to rescue time; d) evaluation of search and rescue methods and organization; 2. We must develop common research protocols for the useful study of future events. We must maximize and share learning from future search and rescue efforts. 3. We must study analagous situations of structural failure and subsequent search and rescue operations. These include: a) construction failures; b) bomb blasts; c) vehicle accidents and d) mine disasters. 4. We must develop realistic performance criteria for location and extrication equipment which reflect the specific physical characteristics of collapsed reinforced concrete buildings and accomodate the condition of injured victims. These performance criteria must then be translated into specific equipment designs. 5) We must develop comprehensive training materials based on worldwide experience but directed toward local application. There must be training both for non-professionals (ie., for self and mutual rescue) and for public safety professionals (ie., fire police, civil defense forces.) Training should include full scale testing of equipment and techniques. Cooperative international training of professionals is important for information exchange and the development of a collaborative capability.

Conclusion: Ideally, in the future all earthquakes will be accurately predicted and populations will take appropriate defensive action. Also, all buildings will be designed and constructed to withstand any earthquake that may occur. However, between now and that ideal future, we have still to endure many building collapses and much suffering. In striving for the ideal, we must not forget the reality. People are the most important, irreplaceable loss from earthquakes. With the application of research and the development of rational methods, significant progress can be made to save lives in the aftermath of earthquakes. It is hoped that international collaboration on research and development projects may be undertaken now to learn from the past and save lives in the future.

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