ORIGINAL RESEARCH

Surviving Collapsed Structure Entrapment after Earthquakes: A "Time-to-Rescue" Analysis

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Abbreviations:
FEMA = [US] Federal Emergency Management Agency
h = hour
USGS = United States Geological Survey

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Abstract

Introduction: Massive earthquakes often cause structures to collapse, trapping victims under dense rubble for long periods of time. Commonly, this spurs resource intensive, dangerous, and frustrating attempts to find and extricate live victims. The search and rescue phase usually is maintained for many days beyond the last "save," potentially diverting critical attention and resources away from the pressing needs of non-trapped survivors and the devastated community. This recurring phenomenon is driven by the often-unanswered question "Can anyone still be alive under there?" The maximum survival time in entrapment is an important issue for responders, yet little formal research has been conducted on this issue. Knowing the maximum survival time in entrapment helps responders: (1) decide whether or not they should continue to assign limited resources to search and rescue activities; (2) assess the safety risks versus the benefits; (3) determine when search and rescue activities no longer are indicated; and (4) time and pace the important transition to community recovery efforts.

Methods: The time period of 1985–2004 was selected for investigation. Medline and Lexis-Nexis databases were searched for earthquake events that occurred within this timeframe. Medical literature articles providing time-to-rescue data for victims of earthquakes were identified. Lexis-Nexis reports were scanned to select those with time-to-rescue data for victims of earthquakes. Reports from both databases were examined for information that might contribute to prolonged survival of entrapped individuals.

Results: A total of 34 different earthquake events met study criteria. Forty-eight medical articles containing time-to-rescue data were identified. Of these, the longest time to rescue was "13–19 days" post-event (secondhand data and the author is not specific). The second longest time to rescue in the medical articles was 8.7 days (209 hours). Twenty-five medical articles report multiple rescues that occurred after two days (48 hours). Media reports describe rescues occurring beyond Day 2 in 18 of 34 earthquakes. Of these, the longest reliably reported survival is 14 days after impact, with the next closest having survived 13 days. The average maximum times reported from these 18 earthquakes was 6.8 days (median = 5.75 days). The event with the most media reports of distinct rescue events was the 1999 Marmara, Turkey earthquake (43 victims). Times range from 0.5 days (12 hours) to 6.2 days (146 hours) for this event. Both databases provide little formal data to develop detailed insight into factors affecting survivability during entrapment.

Conclusions: A thorough search of the English-language medical literature and media accounts provides a provocative picture of numerous survivors beyond 48 hours of entrapment under rubble, with a few successfully enduring entrapment of 13–14 days. These data are not necessarily applicable to non-earthquake collapsed-structure events. For incident managers and their medical advisors, the study findings and discussion may be useful for post-impact decision-making and in establishing and/or revising incident priorities as the response evolves.

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Introduction

During the past decade, structural collapses caused by earthquakes have resulted in >100,000 deaths worldwide.[1] While the majority of survivors of these events are found and extricated quickly, some are subjected to prolonged periods of entrapment before they are rescued.[2] Several factors related to victim survival after earthquakes have been examined, including structure type, victim location in the structure, and victim behavior at the time of the event.[3–5] An extensive literature search, however, indicated very little published research addressing the maximum period that entrapped victims have survived (i.e., maximum time-to-rescue).

The ability to determine maximum possible survival times for missing victims is a critical operational issue for responders, particularly after the failure of massive structures that are not amenable to rapid clearance of debris using hand tools, and swift, thorough searches of all voids. Compared to search and rescue in light, wood-frame structural failures experienced after tornadoes and hurricanes, heavy collapse response traditionally consists of both an initial *search-and-rescue phase* with intensive technical and canine search efforts, and then, relatively slow debris removal that is as safe as possible for trapped survivors. When hope for survivors fades, the response transitions to a *body recovery phase*, with heavy equipment moving large amounts of debris without the time-consuming search efforts. The specter of abandoning deeply entrapped survivors, however, commonly prolongs the search-and-rescue phase of collapsed-structure response. This extended focus may have adverse effects on community-wide priorities, but as long as the possibility of finding a trapped survivor exists, the response efforts and the attention of the affected community remain focused on search and rescue. Therefore, it is vital to determine when hope should be dampened, so that appropriate resources and efforts can be shifted to the remainder of the affected population and to the optimal recovery of the impacted community.

Little formal data exist in the medical or rescue literature to objectively define the length of time victims have survived under the rubble of a collapsed structure. Therefore, the primary objective of this study was to gather reliable, published reports of survivors of entrapment for the purpose of determining the maximum reported survival times in relevant collapsed-structure events. A secondary objective was to identify available details related to survival, and categorize factors that either may promote or preclude extended survival. Because of the extensive number of variables that impact survival across the range of etiologies that cause structural failure (tornadoes, bombings, construction failures, natural gas explosions, mudslides, tsunamis, and others), the authors narrowed the focus of this investigation to collapse from earthquake etiology. Using prospectively designed search and selection criteria, both the medical literature and media reports were searched to identify articles detailing time-to-rescue after earthquakes.

Methods

The period January 1985–February 2004 was selected for investigation. This era, beginning with the Mexico City Earthquake (1985), included a period of advanced, worldwide media capabilities and enhanced attention to seismic events. These factors resulted in more extensive and detailed reporting in both the popular media and the medical literature.

A Medline search of the English language literature was performed using each of the following terms: (1) earthquakes; (2) survivor AND (Boolean) entrapment; and (3) crush syndrome.

Titles of all identified citations were reviewed to pinpoint reports that potentially contained time-to-rescue data for survivors of collapsed-structure seismic events. The culled articles were examined carefully: it was recognized that the primary reason for most reports was not to present time-to-rescue data. Those articles containing survival times were included in the study cohort.

A Lexis-Nexis search was performed on international, English-language media reports describing earthquake responses during the period studied. To identify those that merited further study, the authors initially used the US Geological Survey (USGS) Earthquake Hazards Program list of worldwide earthquakes that resulted in >1,000 deaths.[1] For the study time period, this registry identified 23 separate earthquake events for investigation. For each event, the Lexis-Nexis search was performed using the terms, "earthquake" and "rescue". Due to the search result limits of Lexis-Nexis and the large number of articles, each event was searched using the category "World News" and each of its four available subcategories: (1) North/South America News Sources; (2) Europe News Sources; (3) Asia/Pacific News Sources; and (4) Middle East/Africa News Sources. This resulted in four separate searches conducted for each event. A time interval beginning with the day of each identified earthquake and extending to 30 days post-impact was established for more intensive media scrutiny. Reports that contained information on time-to-rescue of individual victims were selected for further screening.

To identify other earthquake events with survivors of prolonged entrapment during the 1985–2004 study period, a Lexis-Nexis search was conducted for each year, 1985–2004 (exclusive of events already identified by the USGS survey). Lexis-Nexis searches were conducted using the same terms "earthquake" and "rescue". The search results again exceeded the limits of the Lexis-Nexis search engine, and so each search was conducted using the World News category and subcategories listed above. This resulted in four Lexis-Nexis searches for each year of the study with some years separated into four-month segments to avoid exceeding the search engine's capabilities. Then, citations were read carefully for indications of prolonged entrapments.

Recognizing that the media commonly report rescue rumors and uncorroborated stories after major seismic events, the authors prospectively established credibility criteria for the Lexis-Nexis reports. Factors assumed to indicate credibility were: (1) the media dispatch included, in addition to the statement of an extended rescue, the age of the victim, some specific circumstances surrounding the rescue, and the time-to-extrication; and (2) at least two reports from separate news agencies described the same rescue event.

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Location	Date	Estimated Deaths
Mexico	19 Sept. 1982	9,500
El Salvador	11 Oct. 1986	1,000+
Columbia-Ecuador	06 Mar. 1987	1,000+
Nepal-India border	20 Aug. 1988	1,450
Armenia	07 Dec. 1988	25,000
USA (Loma Prieta)*	17 Oct. 1989	65
Iran	20 June 1990	40,000-50,000
Philippines	16 July 1990	1,621
India	19 Oct. 1991	2,000
Turkey*	13 Mar. 1992	498
Egypt*	12 Oct. 1992	552
Indonesia	12 Dec. 1992	2,500
India	29 Sept. 1993	9,748
USA (Northridge)*	17 Jan. 1994	72
Japan	16 Jan. 1995	5,502
Columbia*	08 Feb. 1995	42
Sakhalin, Russia	27 May 1995	1,989
Greece*	15 June 1995	26
Indonesia*	06 Oct. 1995	84
Iran	10 May 1997	1,560
Afghanistan-Tajikistan	04 Feb. 1998	2,323
Afghanistan-Tajikistan	30 May 1998	4,000
Turkey*	27 June 1998	145
Papua, New Guinea	17 Aug. 1998	2,183
Columbia	25 Jan. 1999	1,185
Marmara, Turkey	17 Aug. 1999	17,118
Taiwan	21 Sept. 1999	2,101
Duzce, Turkey*	12 Nov. 1999	683
El Salvador*	13 Jan. 2001	844
India	26 Jan. 2001	20,023
Afghanistan	25 Mar. 2002	1,000
Italy*	31 Oct. 2002	29
Algeria	21 May 2003	2,266
Iran	26 Dec. 2003	26,271**

Table 1—Earthquake cohort identified by study criteria (from the USGS list of earthquakes resulting in >1,000 deaths except where noted); Sources: USGS, Earthquake Hazards Project
* Additional earthquakes identified through Medline and/or Lexis-Nexis searches
** This final death toll was revised down by Iranian government so the number differs from that found in USGS data.

All selected media reports were screened using these credibility criteria before final inclusion in the study. Media reports were considered reliable and included in the study cohort if they passed both standards.

All study cohort reports were evaluated and victim *time-to-rescue data* were extracted. Time-to-rescue was defined as the time elapsed from the seismic activity to the time the patient was extricated and physically removed from the rubble. *When a media or medical report contained exact hours from impact to rescue, these values were reported as both days and hours. When a report described the time interval only as "days after impact", this value is listed alone in the results and text of this paper.*

Reports from both the medical literature and the media also were analyzed using expert judgment to extract potential factors related to victim survival or demise during entrapment.

Results

A total of 34 earthquakes met study criteria and were included in the literature search. The earthquakes, their dates of occurrence, and the estimated number of deaths as an approximation of human impact are listed in Table 1. The number of deaths ranged from 26 to 40,000–50,000.

Medical Literature Review

The Medline medical literature search identified 48 articles documenting times to rescue in trapped earthquake survivors. These articles present medical information for victims of earthquakes in Mexico (1985), Armenia (1988), Loma Prieta, California (1989), Iran (1990), the Philippines (1990), Turkey (1992), Japan (1995), Taiwan (1999), and three earthquakes in Turkey (two in 1999 and one in 2003). The longest time-to-rescue and any survival-related comments from the medical reports of each earthquake are listed in Appendix I. The specificity of the data and the methods of data collection varied significantly between reports. The medical report with the longest reported time to rescue was Klain *et al* reporting on the 1988 Armenian earthquake with one victim saved "13–19 days" after the event (this was based on secondhand data from Soviet authorities and the authors are not more specific).[6] The next longest reported time to rescue was 8.7 days (209 h) as reported by Lopez in a 1989 follow-up evaluation of specific victims from the 1985 Mexico City earthquake.[7] The third longest time-to-rescue reported in the medical literature is 5.6 days (135 h) from the 1999 earthquake in Marmara, Turkey as reported by both Sever and Pocan.[8–10] It should be noted that one article on the 1976 Tangshan, China earthquake was not included in the study cohort since the earthquake pre-dated the study period, even though the report ws published during the search interval (1987).[11] This report includes the description of a rescue at 13.3 days.

In two articles, Noji presents data describing the human impact from the 1988 Armenian earthquake. The first reported information was collected in the week following the earthquake from three towns near the epicenter of the earthquake.[3] The authors gathered case information through interviews with "army, civil defense, and Ministry

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of Health officials, as well as with local firefighters, militia members, army personnel, disaster relief workers, and surviving inhabitants of the region". The vast majority of rescues (90%) occurred within the first 24 hours, with most accomplished by local personnel using simple tools. The last live rescue is reported to have occurred four days (96 h) post-impact. In the second Noji article,[12] data were obtained several months after the earthquake through interviews with local officials and examination of hospital records. This study focused on the circumstances of rescues occurring in a geographic area separate from that described in the first paper. Rescues were divided into those completed after one hour or those accomplished after six hours. This study identified 125 rescues in the period 1–6 hours after impact, with an additional 62 victims rescued after six hours had elapsed. No comment is made on the absolute time to the final rescue.

As mentioned, Klain *et al* also lists time-to-rescue of survivors of the earthquake in Armenia.[6] The data presented in this article are from Civil Defense records collected after the earthquake and are presented in unedited form. Notably, 150 reported rescues were made between Day 6 and Day 12 post-impact. An increase in the number of live rescues on Day 3 and Day 4 is noted, and attributed by the authors to the arrival of heavy lifting equipment such as cranes and bulldozers.

Redmond describes the case of a woman in Armenia rescued after five days. She had given birth while entrapped, but tragically, the newborn had died between her legs as she awaited rescue.[13]

Another seismic event that has received extensive attention in the medical literature is the massive 1995 earthquake in Japan. Tanaka, as an exception to other authors examining this event, presents data from the official report of the City of Kobe.[14] This author reports that seven surviving victims were rescued five days after the earthquake. Other articles report on patient cohorts cared for by specific healthcare institutions or individual medical case reports. Yoshimura *et al* describe six victims who suffered chest injuries, with a maximum reported entrapment time of 3.3 days (80 h) for one patient.[15] Oda *et al* describes another 372 patients treated for crush syndrome and state the time of maximum entrapment to have been 4.4 days (106 h).[16] The majority of these articles present medical patient data focused on initial hospital evaluation, outcome, and treatment. Little field data describing the entrapment details or prehospital medical interventions are offered.

The third earthquake that has received extensive attention in the English-language medical literature is the 1999 Marmara earthquake in Turkey. A single research consortium, which was a coordinated effort between the Turkish Society of Nephrology and the Renal Disaster Relief Task Force of the International Society of Nephrology, produced several of these articles from the same database.[8–10,17,18] As mentioned, the maximum entrapment survival time reported is 5.6 days (135 h) noted by both Pocan and Sever[8–10] and presumably involves the same rescue event. Articles from Ersoy, Yavuz, and Yurugen appear to be from shared data sets as well.[19–21] As with the Kobe, Japan earthquake, these articles primarily present medical patient data after arrival to the hospital, as well as outcome and treatment.

Case report articles include a victim rescued from the freeway collapse five days after the 1989 Loma Prieta, California earthquake.[22] Information on a 4-year-old girl rescued 1.5 days (36 h) after the 1990 earthquake in Iran is provided by Redmond *et al.* It is noted that the victim eventually required amputation of her leg.[23] Angus *et al* provide limited data on 96 victims from the 1992 Turkey earthquake, but only gives time-to-rescue for victims that died either during extrication or shortly thereafter.[24] Sixteen of these victims are described as surviving to be rescued >24 hours post-impact.

Media Literature Review

Multiple media reports met selection and credibility criteria for inclusion in the study. In eight of the 34 earthquakes searched, however, no credible media reports describing rescues were found. Of these eight earthquakes, four occurred in very remote areas of the world, and three of the remaining four impacted pre-2002 Afghanistan. Analysis of media reports on the remaining 26 earthquakes demonstrates maximum entrapment times in each event ranging from 0.33 (8 hours) to 14 days. In 18 earthquakes, rescues accomplished >48 hours post-impact are described, and the longest time-to-rescue for each of these earthquakes is provided in Figure 1. The average of the time of longest entrapment in these 18 earthquakes is 6.8 days (median = 5.75 days). Reports from three of these maximum time-to-rescue events indicate that two persons were rescued simultaneously, for a total of 21 patients. Three of these victims were <10 years of age. Two are described as having died soon after extrication, but information on eventual mortality in the majority of extended rescue cases is not discernable.

Detailed time-to-rescue findings and survival related comments from each earthquake are listed in Appendix II. The number of rescue events for each earthquake reported in the media also is included.

The earthquake with the most extended rescues as described by media reports was the 1999 Marmara earthquake. Media reports cite 39 distinct rescue events, four of which involved the extrication of two persons simultaneously for a total of 43 patients. Times-to-rescue cited in these reports vary from 0.5 days (12 h) to 6.2 days (146 h) after the earthquake. More extensive details are provided in Appendix III.

Most media reports lacked the desired level of detail, but several mention circumstances of entrapment such as access to food and water, or internment in a void space without being pinned by structural debris.

Discussion

The medical and media reports in this study provide a provocative picture, describing a significant number of trapped earthquake survivors rescued >48 hours post-impact, with a few occurring as late as two weeks after the seismic activity. With the exception of one study of second-hand data that are not very specific (13–19 days),[6] no live finds were documented in any earthquake after 14 days had

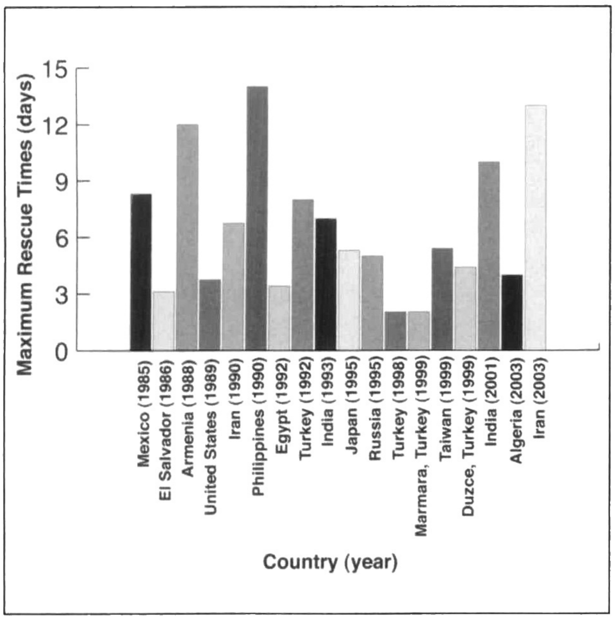

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Figure 1—Earthquakes with maximun resuce times of >48 hours reported in the media (Lexis-Nexis search)

elapsed. In the media reports, a total of five live rescues were accomplished at least 10 days after collapse occurred, and 42 were reported 5–10 days post-impact. These findings may have extensive value in search-and-rescue response strategies, and in the timing of transition from response to community recovery.

A prior literature search by Barbera and Cadoux in 1991 indicated a dramatic drop-off in live finds during the 24–48 hour post-earthquake timeframe.[2] This time period was presented in early training for US Urban Search and Rescue teams as the "Golden 48 hours" analogous to the "Golden Hour" of trauma care.[25] Anecdotally, some non-US collapsed-structure rescue teams operate under the Rule of Fours: a victim can survive four minutes without air, four days without water, and four weeks without food. None of these estimates are based upon extensive research databases or other scientific process, yet valid guidance on maximum time of survival has tremendous importance to responders to such an event. While the findings of this study do not contradict earlier impressions of a drop-off in the number of live finds after 48 hours, the many rescues accomplished, particularly up to five days post-impact, suggest that the intense rescue phase should continue at least through this time milestone.

The medical literature review in this study confirms the general search and rescue observation that the majority of trapped earthquake victims are rescued by local bystanders or local response assets. Most of these victims are "lightly entrapped."[2,6,12] A significant number of earthquake victims, however, remain trapped under complex, heavier structural debris (reinforced concrete and steel) requiring more than simple hand tools to locate and rescue them. Optimal "heavy rescue" response for this type of collapse involves intensive technical and canine search capabilities, careful and deliberate debris removal with specialized tools and structural engineering oversight, physical searches of newly accessible voids, and advanced medical capabilities to treat and stabilize patients during extrication.[26]

These deliberate methods, part of the recently developed "urban search and rescue" science, are necessary for the safety of rescuers and the victims under the debris. Both groups easily can be harmed by shifting debris, dust production, carbon monoxide generated by equipment, or cutting and drilling tools used to penetrate rubble. This slow-paced rescue phase can be followed by a rapid de-layering approach, in which debris is removed more aggressively, with less frequent search intervals, and is used as a transition to the "body recovery" phase in which heavy equipment is used to move large amounts of debris and the time-consuming search effort is abandoned. The relative risk of aggressive debris removal, with the attendant chance of injuring or killing a trapped survivor, always must be balanced against the risk of a survivor dying while still under the rubble. With the improved understanding of maximum survival times and survival factors provided by this study, incident managers may better balance the relative risks in determining when to transition between these response strategies.

The findings of the current study also are valuable in considering when to transition from the overall response phase to community recovery. Knowing, with a high degree of certainty, a point in time when no live victims remain trapped under mounds of debris, is vital for response managers charged with timing this transition. Other factors also argue for the earliest reasonable conclusion of search and rescue activities. Considerations include: (1) collapsed structure rescue work is dangerous, even with optimal safety practices (being able to accurately determine when further risk becomes unwarranted, may minimize overall risk to rescuers); (2) the post-earthquake environment commonly has very limited resources in the face of overwhelming needs—rescue work can consume the attention of critical personnel and equipment—re-focusing them as soon as hope ceases for buried victims could be valuable for attending to other victims' needs; (3) rescue work can delay the community recovery and rebuilding process, with managers focused almost exclusively on search and rescue activity—in many instances, planning for demolition of condemned structures will not occur until the response managers are satisfied that no live victims remain; and (4) tremendous value is placed on each individual's life, and it would be helpful to assure families, loved ones, and the community-at-large that when rescue efforts cease, all hope for survival has been exhausted.

Comparison of the reports in the two bodies of literature (medical and media) examined in this study is interesting. One could hypothesize that time-to-rescue information in the medical literature would be more detailed and accurate than in the media, given the usual attention to accurate detail in medical reporting. This does not appear to be the case, and is understandable when one considers that authors of many of the medical articles did not collect their respective data in the field. They received victim information from other groups, and therefore, information almost always was secondhand. A glaring example is the report of

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one victim that can be identified as the same individual in both the media and medical literature (US, Loma Prieda 1989). Media reports were accurate in describing the rescue occurring at 3.8 days (90 h), as opposed to the five days reported in the medical literature.[22] Progressively, both bodies of literature have become more detailed over the 15-year period of the study. For example, instead of reporting groups of patients with very approximated times to extrication (Armenia), the medical literature has become much more explicit (Turkey 1999). Media accounts of extremely prolonged entrapment cases also have become detailed and provide much more detail on entrapment circumstances when compared to the medical literature. In fact, no medical articles described entrapment factors that contributed to survival during the time to rescue. Only a few medical articles relate even scant descriptions of rescue activities.

Details affecting survival from entrapment within collapsed structures are important to examine. A paramount factor that relates to survival is the collapse pattern itself, since the formation of void spaces as the supports fail and the debris settles may allow trapped victims to survive. The propensity to retain void spaces varies by the type of construction and the building codes: more void spaces remain after the collapse of well-constructed, reinforced concrete, steel, or wood frame buildings compared with un-reinforced concrete, masonry, or adobe construction. The latter type of building structures form few void spaces as the bricks or stones compact. Building codes developed for seismic areas not only are intended to prevent catastrophic structural failure, but also to promote the formation of large void spaces in any structure that does fail. Construction type and poor building code compliance were factors causing the large number of building failures and entrapments in the 1999 Marmara earthquake (Appendix III). The predominant structure type in this region is a reinforced concrete frame as noted by one of the authors who responded with international efforts to assist (AGM). It also is important to note that large household appliances may assist in the creation of survivor void spaces. This appears to have been the case in several media reports (Taiwan and Iran 1990).

The range of collapse patterns expected with each type of structure is well-documented in the Federal Emergency Management Agency's *Structural Engineer Training Manual.*[27] This provides science-based triage guidance for Urban Search and Rescue Task Forces to prioritize collapsed structures based upon the likelihood of void spaces, and therefore, the probability of survivors. This type of information, when used in combination with occupancy data, is essential for rescuers in evaluating structures and assigning search assets. Media reports examined in this study, provide only a few descriptions of structure types from which persons were extricated, and no conclusions can be drawn.

Other factors affecting survival are less well-documented, but also should be considered by responders. Some of these are mentioned peripherally in the media reports collected during this study, but rarely are presented in the medical scientific literature. For example, access to food and/or water is documented in several of the prolonged rescue media reports. The two brothers in Taiwan who survived to 5.4 days (130 h) had access to rain water and rotten apples sitting in a refrigerator that created their void space. The 13-year-old female who survived four days to rescue in Algeria (2003) was reported to have been trapped with the pancakes that she sold for a living. The 97-year-old female who survived nine days in Iran (2003) had access to food that had been next to her before the earthquake occurred. The man rescued from the hotel gym in the Philippines on Day 14 had daily access to rain water while awaiting rescue. Multiple reports also exist of entrapped patients drinking their own urine in an effort to remain hydrated.

Another important factor may be the ambient temperature, which reportedly had great impact on limiting survival after the 1988 Armenian earthquake as "a majority" of rescued victims were suffering from hypothermia.[3] Conversely, a 53-year-old female rescued at 5.8 days (138 h) in Marmara, Turkey was reported to be suffering from hyperthermia (Appendix III). The victim had attempted to place cool bricks near her head as she awaited rescue.

Data exist on the injuries suffered by the survivors of prolonged entrapment from earthquakes, but it is difficult to discern prospectively how, this would help responders when trying to determine when search-and-rescue efforts should terminate. The most feared complication is crush syndrome, which has well-documented clinical features. The articles by Oda *et al* and Shimazu describe the crush syndrome in relation to time to extrication.[16,28] What is not clear is how long someone can survive entrapped with significant crush injury and remain viable. Other injury factors such as airway contamination or prolonged time-to-treatment for injuries remain unexamined. Another important survival issue that could not be assessed in the current study is the rendering of medical care by rescuers during the extrication process. It is well-accepted that a crush-injured victim can deteriorate rapidly and die as the crush-injured area is released from compression. Pre-release treatment for crush injury may prevent the ensuing hypovolemia, hyperkalemia, and acidosis that rapidly can lead to death. Medical care provided immediately after patient extrication also was unclear in the reports examined in the current study.

Earthquake victims commonly are transported to impacted healthcare facilities that cannot provide optimal treatment, thus increasing the likelihood of adverse outcomes. This was demonstrated by the severe lack of functioning renal dialysis capability in Armenia after the 1988 earthquake.[29] Further investigation of these many factors that influence survival from entrapment is warranted.

Extrapolating the data from this study directly to collapse incidents caused by bombings, explosions, or incendiary devices requires careful consideration of the additional human impact factors created by these hazards. Blast effect, fire, heat, smoke, and hazardous material release are common during these incidents, while they are encountered less frequently in seismic events. Prolonged smoldering fire in the rubble of an incendiary impact, for example, creates conditions that produce heat, carbon monoxide, smoke, and other toxins over extended periods. All of these

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effects greatly reduce not just the likelihood that trapped humans will survive the initial impact, but also severely reduce the length of viable entrapment. Collapse events from other hazards such as mudslides, tsunamis, and tornadoes also have additional human impact factors beyond the typical seismic collapse.

Limitations

Several limitations are inherent in this type of study. Most significant is the paucity of details available within each reported case. The lack of extensive victim entrapment detail is not surprising, and is consistent with other data collection experiences in post-earthquake settings. Much of this may be explained by the concept of "perishable data," which is well-understood in the earthquake engineering and disaster sociology research communities.[30–31] The most important findings occur immediately after hazard impact, which typically is the most chaotic time period. Impacted local infrastructure, compromised response systems, and labor-intensive response/rescue thwart orderly collection and retention of details. Careful methodology in capturing or recreating data from this period through retrospective methods such as the effort by the Turkish Society of Nephrology, may lead to a better understanding of this critical response phase. The model of National Science Foundation-funded Quick Response Grants for social scientists is an excellent model for how to fund this critical work.[32]

Another limitation of this study may be in how certain authors reported their time-to-rescue. In some cases, it was unclear whether the number of reported days meant full 24-hour units from time of impact, or included the partial day of entrapment and the partial day of rescue with each counted as a full day. The effect of the latter would have been to increase the reported length of time to rescue by a day beyond the actual entrapment period. Wherever actual hours were reported, these have been presented in both the text and the tables in an effort to clarify these data. Despite this potential limitation, demonstration of extensive survival times are provided in this report.

Eight earthquakes had no English-language media articles reporting prolonged entrapments. These seismic events occurred in very remote areas of the world. Lack of reporting most likely is related to minimal media access to the impacted areas, as well as the lack of any well-organized governmental rescue response in many of these events. Rudimentary response capabilities, both for search and rescue and for emergency medical care, also decrease the likelihood of victim survival from prolonged entrapment. Finally, poor survival rates commonly are associated with dangerous construction features found in developing countries (e.g., un-reinforced stone, adobe, and concrete materials, and few or no construction standards). Rare survivors from these events, however, could have been missed by the design of this study.

Another potential limitation is the validity of media reporting the rescues, despite the credibility checks included in the study design. For example, one news report described a man rescued approximately one month after the 1988 earthquake in Armenia.[33] This report later was discredited, as the victim reportedly lied about being entrapped (with five others) in an attempt to receive more expeditious medical care. It is important to note that data collected for medical reports also may be suspect. Medical investigators commonly obtain the data retrospectively, up to several months post-event. Frequently, the investigators are not from the impacted area and do not describe any safeguards to validate their information. For example, Klain and Tanaka use data provided by the local governments that are not confirmed independently.[6,14] In the authors' experience responding to earthquakes in the US and other countries, the inconsistency between actual details and post-event data collection and interpretation may be dramatic.

The authors recognize that readers may know of other extended survival cases that are not reported in the English-language media or medical literature. The authors, therefore, invite any reader to share other credible reports detailing lengthy entrapment of earthquake survivors.

Conclusions

Drawing from an extensive effort at earthquake data collection, this research demonstrates that structural collapses from earthquakes generate trapped victims who infrequently may survive for 5–6 days. Under special, ideal conditions, survival may extend to two weeks. This information provides an important consideration for incident managers and their medical advisors, who are charged with determining when to transition from the rescue posture to the community recovery mode after an earthquake has caused a widespread collapsed-structure event. The information also may support other decision-making that has important political and psychological implications for surviving family members and the community as a whole. For example, the authors, at the request of the Federal Emergency Management Agency, developed a position paper based on preliminary research of this subject in the days following the 11 September 2001 terrorism attacks. The Federal Emergency Management Agency provided the paper to New York City's Fire Department commanders, and it was a consideration in New York Mayor Guiliani's decision to issue death certificates for missing victims of the World Trade Center on Day 14 post-collapse.[34] For developing countries with very limited resources to expend in fruitless search and rescue activity, this timing is especially important for allocating resources in the post-impact phase.

Finally, the survival findings of this study should be factored into decisions to expend resources for developing and deploying specialized urban search-and-rescue teams designed to respond internationally and at great distances. The delay inherent in activation and deployment to distant and unfamiliar destinations erodes the time-to-rescue window of opportunity, and resources should be used appropriately. That said, the most valuable service provided by highly-qualified urban search-and-rescue teams is not necessarily finding survivors, but rather using the sophisticated structural assessment, advanced search capabilities, and specialized medical judgment to assist the local leaders in limiting the period that focuses primarily on the possibility of trapped survivors. Shortening this time by only one day can have enormous financial and human implications for an affected community and country. This value must be considered in balancing the argument of some authors who state that urban search and rescue teams never are needed internationally since local personnel, using simple equipment, effect the majority of earthquake rescues within 24 hours.[35]

Summary

The data presented in this article demonstrate evidence that many victims survive much longer than 24 hours under heavy rubble. These data can be interpreted as spotlighting the need for specialized response teams that not only perform complicated rescues, but have sophisticated search capability to rapidly find survivors or rule out the possibility that live victims remain within the collapse debris. Further investigations are needed, ideally with prospectively designed data categories, to more fully understand the factors affecting maximum possible survival times for trapped victims.

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Appendix I—Medical literature reports of rescued survivors with maximum entrapment time and associated details presented in article (h = hours; pt = patients) *continued*

Earthquake	Year	Reference	Maximun Entrapment Time (days)	Maximum Entrapment Time (h)	Associated details
Mexico	1985	7	8.7	209	n = 10 100 to 209 h
Armenia	1988	36	5	---	In discussion of crush syndrome, mentions one case report
		6*	"13-19"	---	13-19 days = 1 6-12 days = 150 5 days = 1,757 4 days = 5,682 3 days = 4,825 2 days = 1,660
		3	4	96	5 pt at 96 45 rescued at 72 50 rescued at 48
		12*	>5	---	"several rescued more than 5 days" >6 h = 72 >1 h = 153
		13	5	---	Case report
USA (Loma Prieta)	1989	37	0.2	5	Brief description of rescue efforts
		22	5	---	Brief description of rescue efforts
Iran	1990	38	0.3	8	No time under rubble for other n = 496 pt
		23	1.5	36	Brief description of rescue efforts
Philippines	1990	39*	2 rescued >2 days	48	n = 235 "<1 hour to >48 hours"
Turkey	1992	24*	16 rescued >1 day	24	n = 96 (Only times for who died during or after extrication) 1 to >24 h
Japan	1995	40	0.8	20	Case report
		41	2.1	50	n = 8 1-50 h
		42	0.3	8	Case report
		43	0.8	20	n = 42 3-20 h
		44	Mean 0.4	9.9	n = 18 Only mean with SD times reported
		45	0.3	8	n = 6 3-8 h
		46	0.1	3	Case report
		47	0.6	15	n = 8 1-15 h
		16	4.4	106	n = 372 1-106 h
		28	1	24	n = 14 1-24 h
		14	5	---	5 days = 7 4 days = 14 3 days = 89 2 days = 129
		48	0.4	10	n = 35 1-10 h
		15	3.3	80	n = 63 "few hours" to 80 h

* Author is not more specific about rescue time, reporting approximate time frames.

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Appendix I—Medical literature reports of rescued survivors with maximum entrapment time and associated details presented in article (h = hours; pt = patients) *continued from page 13*

Earthquake	Year	Reference	Maximun Entrapment Time (days)	Maximum Entrapment Time (h)	Associated details
Turkey (Marmara)	1999	49	3	72	n = 18 45 minutes to 72 h
		50	2.5	60	n = 17 4.5-60 h
		51	4.1	98	n = 20 3-98 h
		52	0.8	18	n = 16 6-18 h
		53	mean = 0.6	13.6	n = 10
		19	3	---	n = 60 3h to 3 days
		54	4.5	110	n = 33 1-110 h
		55	mean = 0.4 (9.4 h for patients requiring dialysis) mean = 0.8 days for "responders to medical treatment"	9.4 (19.1)	n = 59 dialysis patients n = 28 "responders to medical treatment"
		56	3.3	80	n = 60 2.5-80 h
		57	3.3	80	n = 40 4-80 h
		58	1	24	n = 9 6-24 h
		59	0.4	9	Incomplete data from 21 Izmit and 6 Duzce
		10	5.6	135	n = 630 6-135 h
		60	3	72	n = 51 3-72 h
		17*	7 rescued >3 days	72	n = 477 "<1 to >72 hours"
		8	5.6	135	n = 539 0-135 h
		9	5.6	135	n = 539 0-135 h
		18	mean 0.6	14.5	n = 423 Only mean with SD times reported
		20	3	72	n = 59 3-72 h
		21	3	72	n = 60 3-72 h
Taiwan	1999	61	1.3	31	n = 95 0.1-31 h
		62	0.02	0.5	Case report
Turkey (Duzce)	1999	59	See above		See above
Turkey	2003	63	0.7	17.3	n = 16 3.3-17.3 h

* Author is not more specific about rescue time, reporting approximate time frames.

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Appendix II—Media reports of rescued survivors (m = months old; n = number of extended rescue events reported; y = years old) *continued*

Earthquake	Year	n	Longest reported time to rescue	Second longest time to rescue	Third longest time to rescue	Associated details reported in the articles
Mexico	1985	13	8.3 days/200h** (infant)	8 days/192 h (infant)	6.7 days/161 h (infant)	Infants trapped in collasped hospital
El Salvador	1986	3	3.1 days/75 h (33 y male)	3 days/72 h (22 y female)	2 days/48 h (6 y female)	Male at 3.1 days required leg amputation
Columbia-Ecuador	1987	-	-	-	-	---
Nepal-India border	1988	-	-	-	-	---
Armenia*	1988	6	12 days (16 y male)	10 days/240 h (62 y female)	8 days (30 y female and her 3 y child)	62 y female reported critical upon extrication-no follow-up available
USA (Loma Prieta)	1989	2	3.8 days/90 h (57 y male)	0.3 days/7 h (6 m male)	-	57 y male trapped in car on evevated freeway
Iran	1990	6	6.8 days/162 h (9 y male)	5 days (40 y female with 12 y son)	4.5 days (6 y male)	9 y.o. reported to be comatose upon extrication 6 y.o. male near refrigerator void space
Philippines	1990	4	14 days (27 y male)	11.2 days/269 h (27 y male and 21 y female)	1 day (14 y male)	14 day and 11.2 day victim reported to have access to rain water
India	1991	-	-	-	-	--
Egypt	1992	1	3.4 days/82 h (36 y female)	-	-	Patient reported extreme heat while awaiting extrication
Turkey	1992	1	8 days (22 y female)	-	-	Noted to have renal failure after taken to hospital
Indonesia	1992	-	-	-	-	--
India	1993	4	7 days (35 y male)	7 days (7 y female)	4.3 days/104 h (18 m female)	35 y discovered to be alive just as placed on funeral pyre; 18 m discovered under cot
USA (Northridge)	1994	8	0.3 days/9.5 h (43 y male)	0.2 days/5 h (67 y male)	0.2 days/h 5 (45 y male)	Several victims required equipment beyond hand tools to rescue
Japan	1995	27	5.3 days/128 h (66 y male and 78 y female)	4.4 days/106 h (79 y male)	4.4 days/105 h (67 y male)	--
Columbia	1995	1	0.9 days/22 h (22 y female)			Dies during extrication
Sakhalin, Russia	1995	8	5 days (22 y male)	5 days (33 y male)	4.2 days/100 h (23 y female)	-
Greece	1995	1	1.8 days/44 h (8 y male)	-	-	Dehydrated, but otherwise stable
Indonesia	1995	1	2 days (37 y male)	-	-	---
Iran	1997	2	1.1 days/27 h (32 y male)	-	-	---
Afganistan-Tajikistan	1998	-	-	-	-	---

* One exremely lengthy entrapment was reported by subsequently found to be fabricated in a fraudulent attempt to receive medical care

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Appendix II—Media reports of rescued survivors (m = months old; n = number of extended rescue events reported; y = years old)

continued from page 15

Earthquake	Year	n	Longest reported time to rescue	Second longest time to rescue	Third longest time to rescue	Associated details reported in the articles
Afganistan-Tajikistan	1998	-	-	-	-	---
Turkey	1998	2	2 days/49 h (35 y female)	1.1 days/26 h (11 y male)	-	---
--Papua, New Guinea	1998	-	-	-	-	---
Columbia	1999	1	2 days (16 y male)	2 days (12 y male)	-	---
Marmara, Turkey	1999	39	6.2 days/146 h (4 y male)	5.8 days/138 h (53 y female)	5.5 days/133 h (18 y female)	4 y male received intravenous fluids during extrication
Taiwan	1999	10	5.4 days/130 h (20 and 25 y brothers)	3.8 days/91 h (4 m female)	3.6 days/87 h (6 y male)	Brothers trapped next to refrigerator with food; water was available from spraying of buildings
Duzce, Turkey	1999	6	4.4 days/105 h (42 y female)	1.7 days/41 h (48 y female)	1 day/25 h (19 y male)	42 y reported to have crush syndrome from arm injury
El Salvador	2001	1	1.4 days/33 h (22 y male)	-	-	Dies after extrication
India	2001	28	10 days (male and female siblings in their "50s")	8 days (11 m female)	8 days (17 y male)	Siblings trapped in large void with access to food 17 y male trapped in well
Afganistan	2002	-	-	-	-	---
Italy	2002	2	0.7 days/16 h (9 y male)	0.1 days/3 h (7 y male)	-	One schoolhouse impacted by earthquake
Algeria	2003	8	4 days (13 y female)	4 days (5 y females)	3 days (11 y female)	13 y female survived eating pancakes she was entrapped with 11 y dies during extrication due to secondary collapse of structre
Iran	2003	11	13 days (56 y male)**	9 days (97 y female)	6 days/144 h (27 y male)	97 y female was in void created by bed with access to food; 56 y male dies in field hospital

** Victim reported to die of subsequent injuries after extraction

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Appendix III—Media reports of rescued survivors, 1999 Marmara, Turkey Earthquake (F = female; M = male)

Age (in years)	Gender	Time to rescue (days)	Time to rescue (hours)	Comments in report
7	M	0.5	12	Both legs broken as a result of collapse
10	F	0.5	13	Was lying next to dead friend awaiting rescue
4 months old	F	1.0	24	Ambient temperature was 88 degrees F during rescue
18	M	1.3	30	Screaming to attract rescuer attention
6	M	1.5	36	Started on 6th story, building collapsed "sideways"
13	F	1.5	36	---
59 and unknown age	M/F	1.7	40	Husband trapped under cantilever formed by bed
45	F	1.8	44	Reported to have no injuries
38	M	1.9	45	---
15 days old	F	2.0	48	---
47	M	2.0	49	Reported to have no injuries
9	F	2.3	56	---
7 and 3 siblings	M/F	2.4	57	Rescued from a collasped 14 story building
74	F	2.4	58	---
23	F	2.4	58	---
8	M	2.4	58	---
27	F	2.4	58	---
67	F	2.5	61	Sleeping on 5th story at time of earthquake
43	F	2.7	64.25	---
8 months old	F	2.8	67	Ambient temperature reported as 100 degrees F
36	M	3.1	74	Awake at time of extrication
3	F	3.1	75	---
31	F	3.3	80	Awake with "scratches", trapped in void, started on 5th floor of 7-story building
17	F	3.4	81	---
39	M	3.5	85	---
29	F	4.0	--	---
40	M	4.0	97.5	Awake, trapped on back, unable to roll over, wet lips with own urine
10	F	4.1	98	---
95	F	4.1	98	---
26 and 5 aunt and niece	F/F	4.2	100	Both with unspecified leg injuries, rescued from collasped 5-story building
11	F	4.2	100	---
9	M	4.6	110	Unspecified medical care given during extrication
70	F	4.8	115	---
19 and 10 sisters	F	4.8	116	---
50	F	5.0	--	---
57	F	5.5	131.5	Patient had prior history of stroke
18	F	5.5	133	Trapped in position in which could neither stand nor lie down, 11-story building
53	F	5.8	138	Shielded by armoire that killed husband, patient had diabetes
4	M	6.2	146	Awake at time of extrication, received intravenous fluids during extrication

Editorial Comments

Time, Space, and Earthquake Survival: A New "Special Relativity"

In an attempt to shed light on the question of when to terminate search and rescue activities, the authors conducted a massive review of both the scientific and popular media literature concerning reports of earthquake deaths and length of entrapment time as a factor for survivor recovery. Let's look at these two parameters separately: deaths, and time-to-live extrication.

In order to consider the number rescued alive following an earthquake to those who died in it, we first have to settle on something of an operational definition of death. This might seem a bit outlandish, death being such an incontrovertible endpoint, but consider the issue of earthquake related deaths following the 1994 Northridge, California earthquake. The reported figure included by the authors is 72. But there have been varying reports of the number of dead published in different sources. Perhaps the most accurate was by Peek-Asa, who did a hands-on review of both hospital and coroner medical records. Results of that inquiry identified only 33 deaths, less than half as many as cited, and the majority of whom died in the structural "pancake" collapse of an apartment building near the epicenter. (*International Journal of Epidemiology*, 1998;27(3):459-465). If an agreed upon number of fatalities attributable to the earthquake was not possible in a highly sophisticated emergency medical services and public health vital records system such as existed in Los Angeles in 1994, figures from less developed regions that chronicle massive numbers of reported deaths must be weighed very carefully.

Similarly, there is a vast range of times from impact to live extrications across earthquakes. The range is wide, and it underscores the difficulty identified by the authors regarding a management decision to transition from rescue to recovery. Each situation is unique, and among the many variables that impact injury and death following an earthquake are structural engineering and construction practices, soil conditions, magnitude of the earthquake with relevant ground motion, structural collapse patterns, proximity to epicenter, time of day, occupancy of failed structures, and the cultural practices of the community impacted. The authors cite the shortest "survival to maximum entrapment time" as reported by Nakata following the 1995 Kobe, Japan earthquake (three hours), with the longest reported by Tanaka (five days). In the 1989 Armenia earthquake, with different construction practices and seismic magnitude, Klain reported survival following extrication from 13–19 days post-quake.

Thus, to make broad-based recommendations based on the reports reviewed in this paper, of when to absolutely discontinue search and rescue operations (five days, 5–10 days, 14 days) is difficult. This study presents experiences from a number of earthquakes from diverse communities, from scientifically variable publications. While these reports might provide some insight for those from similar settings who are charged with making management decisions, the ultimate judgment remains with the local emergency managers as to when to move from rescue to community-wide recovery. Factored into that judgment must be the triaging of resources that might be directed to a potentially very small number of entrapped individuals, thereby diverting them from recovery and relief operations for a very large number of displaced or injured survivors. Not an easy one to sleep with...

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Author Reply

The authors of this manuscript are pleased to note that the above editorial comments appear to strongly support what we have proposed as a major operational issue related to collapsed structure events. As this particular reviewer points out, the data generated by these events commonly are problematic, and even a basic denominator such as the number of deaths for a specific event can be difficult to conclusively determine (as an example, the USGS-reported death toll in the Bam earthquake is much higher than the host country data (Table 1 of our article)). This phenomena is one component of "perishable data" that is discussed in our article, but by no means indicates that available data should not be examined critically. Careful attention to assessing reliability of data, however, must be accomplished as was demonstrated in our report.

In reference to validity of the data, it is most interesting to the authors that much of the data in the medical literature seemed just as suspect, if not more so, than media reports. As discussed in our article, this most likely is due to the fact that medical reports utilized field data that primarily were of second-hand nature. With the rapid response and extensive mobility of modern news media, it is clear that the media obtains its information from sources much closer to the extrication scenes. If any reader remains skeptical, you are invited to check some of the online media reports, as many provide actual pictures and video feeds of the rescues as well as the written details.

The authors completely agree with the editorial comment referencing the "uniqueness" of each collapsed structure "situation." The discussion in the paper proposes even more parameters to consider than those presented in the

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editorial. For example, in addition to the construction type, soil, and other details mentioned by the reviewer, the structural-collapse type and the capability to provide medical care during extrication are all important factors for consideration. These parameters all contribute to event "uniqueness". In raising a caution about "broad-based recommendations", perhaps the reviewer misunderstood the manuscript statement "it appears that collapsed structure consequences generate trapped victims that not infrequently survive for 5-6 days. This information provides an important consideration for incident managers charged with determining when to transition from the rescue posture." A fair interpretation of this statement is a broad-based "consideration", not a broad-based "recommendation".

Having participated in major decision processes during large-scale incidents, we completely concur with the difficulty of any transition-to-recovery decision. We agree with the editorial statement: "Factored into that judgment must be the triaging of resources that might be directed to a potentially very small number of entrapped individuals, thereby diverting them from recovery and relief operations for a very large number of displaced or injured survivors". In our experience, this "judgment" often is based upon anecdotes and misconceptions, and indeed, attention and resources commonly are over-triaged towards looking for survivors under the rubble. Because of this perspective, we undertook this academically rigorous effort to provide objective, reliable information for those decision-makers.

Invariably, medical authorities at large-scale collapsed-structure incidents will have to field the question we have faced several times: "Can anyone still be alive under there?"This report provides some objective basis upon which the medical authority can provide input into the incident management decision-making process. It is by no means an argument either for or against simplifying decision-making, or an attempt to remove the decision from appropriate incident management authorities.

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