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BEHAVIOR OF VICTIMS TRAPPED IN COLLAPSED STRUCTURES: SUMMARY OF FINDINGS

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Summary of Findings

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Behavior of Victims Trapped in Collapsed Structures. Summary of findings.

The importance of knowledge of human behavior during disasters has been traditionally recognized at a meso level. Social scientists and other disaster researchers have mainly explored human behavior at the level of the community, and not of a particular individual. More is known about the performance of building structures during disasters than about the behavior of building occupants. Indeed, the search in the scholarly and professional literature[1] yielded only a few results dealing extensively with the behavior of particular individuals located in specific buildings during various disasters (Aguirre 1995; Durkin 1985, 1987, 1988). Relevant information about trapped victims is found within an intersecting terrain of a range of disciplines: engineering, architecture, the social sciences, disaster epidemiology and other medical sciences.

The results of the literature search were broader than the particular behavioral patterns of trapped victims and covered a number of adjacent issues. In summarizing the findings of studies in this area I will to some extent rely on the classification system developed by Aroni (1983). In his analysis of earthquake injuries he grouped a multitude of influencing factors around four categories: human factors, physical factors, socio-economic and circumstantial factors. *Physical factors* incorporate characteristics of the built environment, as well as the behavior of non-structural elements. *Human factors* include personal characteristics such as age, sex, and state of health. *Circumstantial factors* include such things as the time of day and season of the year the earthquake

[1] The search was performed using a variety of key terms (e.g. "collapsed buildings," "structural collapse," "trapped victims," "voids/void spaces," etc) in a number or electronic databases (SocAbstracts, Ingenta, LexisNexis, Google, etc.) and several on-line catalogs of publications (Learning Resource Center of US Fire Administration; Resource Collection of the Disaster Research Center at the University of Delaware, Newark; Natural Hazards Center at the University of Colorado, Boulder; Hazard Reduction and Recovery Center at the Texas A&M University, etc.).

occurs, and *socio-economic factors* embrace both institutional factors, cultural aspects and the varied circumstances of families and communities.

Using Aroni's classification as a guide I first examine the literature on structural collapse addressing issues of vulnerability of buildings in general as well as of particular construction types and building elements and patterns of void spaces' creation. I then proceed to summarize the structural, institutional and social factors affecting the safety of building occupants during disasters. The remaining part of this paper deals with the psychological and behavioral patterns of community residents in general and trapped victims in particular during disasters.

Physical factors: Structural vulnerability and epidemiology of disasters.

Trapped victims are most often discussed in the context of structural collapse and resulting injuries sustained by the individuals. The majority of studies in this area are focused on earthquakes as the type of disaster that produces the most extensive structural damage, but there are several studies that consider other types of natural and man-made disasters (Sparks 1985).

The limited scope of this summary does not allow for an in-depth analysis of a multitude of studies that explore structural vulnerability of buildings to disasters[2], taking into account a multitude of factors - e.g. the variety of construction types, material and quality, the geology of the area, the distribution of shaking intensity. Therefore, it is only

[2] A wealth of information on the subject is found on the web-site of the Multidisciplinary Center for Earthquake Engineering Research (http://mceer.buffalo.edu/publications/default.asp) and in the Proceedings of the U.S. National Conference on Earthquake Engineering (may be obtained through interlibrary loan or purchased on-line at http://www.eeri.org/cds_publications/catalog/index.php?cPath=23_30)

possible to briefly outline the characteristics of various building structures, associated modes of failure, and the consequences of building collapse.

There is a common agreement in the literature that the type of building and the collapse patterns are important determinants for morbidity (Glass 1977, Noji 1990, Meli 1988). Data on earthquakes and other disasters suggests that a relatively small number of damaged structures are the source of the vast majority of the serious casualties (Coburn et al. 1992). For example, 50 of 62 deaths in the Loma Prieta earthquake occurred at the Cypress freeway structure in Oakland, and 40 of 64 deaths in the 1971 San Fernando earthquake occurred as a result of a collapse of a Veterans Hospital (Noji 2003).

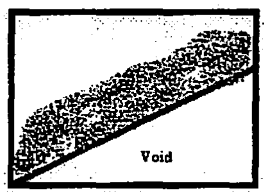
Tiedemann (1989) lists a number of important variables that impact the behavior of buildings during disasters and, therefore, affect the number of casualties:

- Resonance between predominant frequencies of the foundation material and of the building structure;
- Quality, i.e. predominantly hardness of the foundation material;
- Shear strength of the building resulting from the combined strength of structural and non-structural parts;
- Compatibility of behavior of building materials and components under dynamic loads;
- Regularity and symmetry as regards floor plans, elevations, shear strength, distribution of masses and damping;
- Type and behavior of non-structural elements - their design, quality arrangement and fastening;
- Hammering between buildings;
- Orientational sensitivity, and
- Liquefaction.

These factors determine the vulnerability of buildings to disasters as well as provide clues as to where void spaces might occur, and thus where surviving victims might be found. The types of collapse generate known pattern of void spaces in the rubble. Search and

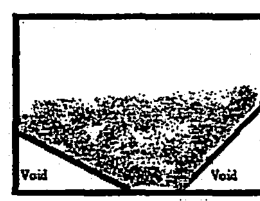
Rescue literature discusses several types of collapse voids, which represent the single most important factor in determining the likely location of trapped victim and offers the victim the greatest chance for survival. For example, the Manual for the International Fire Service Training Association (Murnane 2003) outlines five types of collapses:

Lean-to collapse is formed when one exterior wall collapses, leaving the floor supported



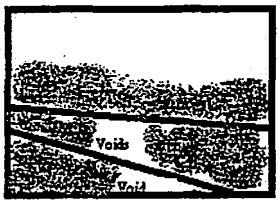
at one end only. In case of an unsupported lean-to collapse, the victims are likely to be found in the lower portion of the lean-to or positioned on the floor below the unsupported lean-to. Caution is warranted for removal of debris that is supported at the "base" of the lean-to collapse, which can cause the floor to slide, collapsing the void. In the case of a supported lean-to collapse, most likely the victims will be located at the bottom of the lean-to near the wall surrounded by rubble; victim could be on the floor below the collapsed floor under the large void created at the opposite end of the failed construction. Victim survival profile is low to medium.

V-shape collapse occurs when an interior supporting wall or column fails. Victims who will be on the floor below, located only a few feet from these areas, will usually have a higher



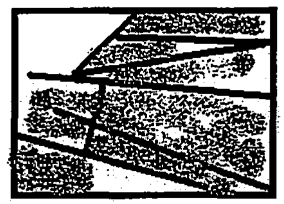
survival rate due to the sheltering effect of the collapse floor (prevents rubble landing on them). Victims on the top of the collapsed floor usually are: at the bottom or near the center of the V; trapped in the debris in various places. Due to large amount of debris concentrated in one area, survival rate for victims in this area is low.

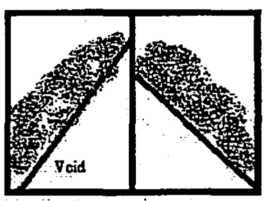
Pancake collapse is formed when all vertical supporting members fail and most of the



floors collapse on top of one another. This is more probable in heavy-floor buildings. This kind of collapse might not move the victim horizontally at all; it may drop the victim straight down in the collapse pile; victim may be located on several floors anywhere in the debris. Victim survival rate is very low.

Cantilever collapse: This type of collapse is similar to the pancake pattern with the additional problem of some of the floor planes extending, unsupported, from the debris pile. Victims might be found under the floor as in the pancake condition.





A-frame collapse: The highest survival rate is for victims located near the partition wall at the center of the collapse. Victims located on the floor above can be pinned in the debris near both exterior walls, which results in lower survival rate.

There is also some information on the vulnerability of particular building structures. Eric Noji (2003) states that by far the greatest proportion of earthquakes' victims have died in the collapse of unreinforced masonry buildings or unreinforced fired-brick and concrete-block masonry buildings that can collapse even at low intensities of ground shaking and will collapse very rapidly at high intensities. Other studies also support this conclusion (Sparks 1985). Unreinforced masonry buildings are from one to six stories in height and may be residential, commercial, industrial. Their primary weakness is in the lateral strength of the walls and the connections between the walls and the floor or roof assemblies. Collapses are usually partial and are caused by the heavy, weakened walls falling away from the floors. Falling hazards are very widespread at these buildings due to the amount of small, loose masonry components that results from the collapse. At the same time large angular voids form, because large sections of floor or roof often stay together as a plane.

Adobe structures have performed very poorly in many highly seismic parts of the world (e.g., eastern Turkey, Iran, Pakistan, Latin America. (Noji 2003, Ceciliano et al 1993). These buildings not only have collapse-prone walls but also very heavy roofs that prove to be deadly to people when they collapse.

On the other end of the spectrum of building vulnerability are wood-frame buildings, which usually comprise residential housing. They have been declared as one of the safest structures during an earthquake, because, despite their weakness to resist lateral forces and consequent collapse, they are constructed of light wood elements, and their potential to cause injury is much less serious than that of unresistant old stone buildings (Noji 2003). The study of the 1995 Hanshin-Awaji earthquake in Nishinomia City (Lu Hengjian et al. 2000) has concluded that most casualties occurred in relatively old two-story wooden buildings in which the ground floor collapsed completely without survival space. More than 84 percent of casualties occurred in buildings that collapsed without survival space.

Concrete-framed houses are generally safer in terms of their resistance to collapse, but they are also significantly more lethal and kill a higher percentage of their occupants than masonry or wooden buildings. As Noji (2003) points out reinforced concrete requires sophisticated construction techniques; however, it is often used in communities around the world where either technical competence is insufficient or inspection and control are inadequate. Catastrophic failures of modern reinforced, concrete-slab buildings caused by the collapse of their supports have recently been described in Mexico City (1985), El Salvador (1986), and Armenia (1988) (Bommer and Ledbetter 1987, Wyllie and Lew 1987). The principal weakness of concrete frame building (heavy floor) is the poor column reinforcement and inadequate connections between floor slabs and columns. Collapse from the failure of these parts can be partial or complete. These structures often fall down on themselves, or they may fall laterally if the columns are strong enough. Meli (1988) states that the failure of vertical members is worse than the failure of horizontal components; to avoid a catastrophic collapse it is necessary to preserve the "main vertical load-resisting elements." Whereas the debris of buildings of adobe, rubble masonry, and brick can be cleared with primitive tools, reinforced concrete represents serious problems for rescuers, and requires special and heavy equipment.

Other types of buildings discussed in these studies are precast concrete buildings, whose primary downfall is due to the weakness of the connectors between building parts such as floors, walls and roof; and heavy wall tilt-up/reinforced masonry. The later have gotten mixed reviews as to their resistance to earthquakes (Cole 1991). Walls in these structures usually fall away from the roof or floor edge, but because they are very strong panels, the top of the wall will fall far away from the building.

Several empirical studies evaluated the comparative performance during disasters of buildings of older and newer construction (Hengjian et al. 2000, Cole 1991). Thus, during the Loma Prieta earthquake relatively modern buildings performed much better than buildings of pre-1973 construction. Most of the significant structural damage suffered by modern residences was due to the collateral effects of earth movement, i.e. land sliding and soil rupture. Although this particular earthquake was not a good test of the buildings due to its moderate intensity, Cole speculates that buildings designed and constructed to current codes would have fared well during a stronger, longer duration earthquake. On the other hand, residential buildings of older "archaic" construction suffered extensive damage.

Another important structural risk factor for disaster morbidity is the height of the building (Noji 2003). In the 1988 Armenian earthquake, people inside buildings with five or more floors were 3.65 times more likely to be injured compared to those inside buildings less than five floors in height (Armenian et al. 1992), and in the 1990 Philippine earthquake, people inside buildings with seven or more floors were 34.7 times more likely to be injured (Roces et al. 1992). As Coburn et al. point out (1992) in a high-rise building, escape from upper floors is improbable before the building collapses, and if it collapses completely, nearly 70% of the building occupants are likely to be trapped inside. In a low-rise building that takes perhaps 20 or 30 seconds to collapse, more than three-quarters of the building's occupants may be able to escape before the collapse.

In addition, research has shown that the location of people in the building at the time of the disaster is an important determinant of morbidity (Noji 2003). For example, occupants of upper floors of multistory buildings have been observed to fare less well than ground-floor occupants. In Armenia, there was a significant increase in risk for injury associated with the floor people were on at the moment of the earthquake. People on the second to the fourth floor at the time of the earthquake were 3.84 times more likely to be injured than those on the first floor, and those on the fifth floor and higher were 11.20 times more likely to be injured (Armenian et al. 1992).

Another important aspect mentioned by the literature in this category is the performance of non-structural elements during disasters, which include partitions, ceilings, windows, equipment, machinery, fixtures, casework, piping, ducts, roof tile, etc. Traditionally criteria for evaluating structural safety have been tied to the structure itself (Stubbs and Sichorsky 1987). However, nonstructural failures (collapsing of cladding or partitions) can also cause substantial harm and should be physically connected to the structure (Cole 1991, Jones et al. 1990).

Circumstantial and socio-economic factors.

The occurrence of human casualties in disasters is dependent not only on the characteristics of the disaster and characteristics of the building stock, but also on the cultural, social and behavioral characteristics of the affected population (Aguirre 1995; Pomonis et al. 1991; Durkin 1987). Occupancy of the building by time of day and season is important in determining occupant exposure to specific hazards (Durkin, 1987; Tiedemann 1989). Kuwata and Takada (2002) in their study of the 2000 Western Tottori earthquake noted the low occupancy of buildings at the time of the disaster. The earthquake occurred at 1:30 pm on a weekday, meaning that the inhabitants of the building were awake and at once perceived the dangers of the earthquake. In addition, on a weekday afternoon the majority of people were not at home - the inhabitant occupancy was estimated at 27%.

Knowing the time of the disaster helped Michael Durkin to reconstruct the location of his study's subjects during the 1985 Mexico earthquake: the impact had occurred at 7.17 am, when most of the medical students were in their dorm room preparing for the day, or on their way to the cafeteria for breakfast. Those who had morning shifts were already at work when the hospital collapsed.

Another issue directly related to community's culture and social relations is the increased vulnerability to disasters of minority group members and residents of low-income households. As Tierney et al. (2001) points out these categories of people have lower ability to protect themselves from disaster. Income is positively related to access to better and safer housing. Older, unreinforced masonry buildings, which are highly susceptible to collapse in earthquakes, and mobile homes constitute an important source of affordable housing for lower-income residents in earthquake prone cities like San-Francisco and Los Angeles.

Behavior of community residents, building occupants and trapped victims during disasters.

Studies in this section cover a wide array of issues ranging from general behavioral patterns of communities during disasters to what building occupants did during the actual period of a disaster and experiences of trapped victims. The much-feared social disorganization during the disaster periods is extremely rare (Tierney et al. 2001; Dynes, 1970; Durkin, 1986; Aguirre, 2005). Conditions under which panic does occur have been identified in the literature (Dynes, 1970; Quarantelli, 1977; Quarantelli and Dynes 1972; Johnson 1988).

It is an atmosphere of human solidarity and cooperation that characterizes the behavioral processes during and in the aftermath of a disaster. Residents of disaster-stricken areas are proactive and willing to assist one another. Research findings show that volunteer activity increases at the time of disaster impact and remains widespread during the emergency period (Dynes, Quarantelli, and Wenger, 1990). During the Guadalajara Gas explosion community residents who weren't trapped or freed themselves from entrapment went to great lengths in searching for their kin and neighbors (Aguirre 1995). There were instances when individuals would call attention to other victims who were trapped nearby and could not free themselves; they would also speculate about the possible location of other victims, provided rescuers with information about the inner settings of the house, or reconstructed the architectural topography of the street turned to rubble.

Furthermore, Aguirre (1995) after surveying the victims of the explosion concludes that "the behavior of the victims ... was marked by the continuation of preexisting motivational, normative, and value orientations. Victims, under the very difficult conditions of being buried alive, often in imminent danger of death, continued to be social beings. ... their actions during entrapment showed the constraint generated by their membership in primary groups and other meaningful social categories." Sometimes the victims, when trapped, were able to hear what was going on above or next door and thus maintained social ties with the world around them. They also engaged in imaginary interaction with significant others and saints seeking spiritual and psychological support, which is so important for survival.

Several studies pay particular attention to the importance of family as an institution, and its role is emphasized during a crisis or an emergency (Aguirre 1995; Alexander 1990). Family is a very powerful unifying factor for disaster victims, and, as Alexander points out, its influence could immediately dissolve other groupings such as friends. Family members are the first to be rescued by their kin. As soon as the nuclear family is reunited they concern themselves with other relatives. Second comes the concern for immediate neighbors and other nearby residents, and then other people farther removed from their spheres of everyday interactions (Aguirre 1995). An important research finding is cited by Aguirre - the chances of people surviving the explosion were directly proportional to the presence among the searchers of a person or persons who cared for the victim and who knew the victim's possible location at the time of the explosion. Another important related pattern is that the significant others acted as proxies for the victims reminding the searchers that the family member was missing, and supplying information about their possible location.

Behavior of building occupants.

The most comprehensive studies of occupant actions during disasters and, consequently, trapped victims' behavior were the ones done by Benigno Aguirre on the Guadalajara gas explosion and by Michael Durkin on the aftermath of 1979 El Centro, 1985 Mexico and 1991 San Fernando earthquakes.

The apparent leitmotif of victims' behavior - be it spontaneous actions, actions based on prior training, or organized response – is to ensure their safety or increase their chances of survival and rescue. Literature suggests that victims behave actively and assume responsibility over their rescue to the extent that they can do so. Thus victims trapped as a result of the Guadalajara gas explosion moved their bodies ever so slowly to create more room in the rubble; others called attention to themselves by screaming of making noise on the nearby debris (Aguirre 1995). Seven of the eighteen victims trapped in the dormitory after the 1985 Mexico earthquake attempted to free themselves (Durkin

1987). However, only one of them managed to free his trapped foot, move debris out of the way and get to the exit. When asked about the nature of their entrapment, eight respondents said that part of their body was trapped by falling rubble, leaving them very constrained for any maneuver. This predetermined whether or not they attempted to free themselves and how successful they were.

Prior experience proved to be important in increasing the levels of preparedness and more effective performance during the response period (Durkin 1987). However, studies suggest that many general beliefs about appropriate response can endanger rather then protect building occupants – for example, trying to leave the building may put one in an increased danger during the collapse (Durkin and Murakami 1988). A different example involves a person who moved into the doorway as the shaking began (as she was advised to do during earthquakes), and was hurt by the door being slammed shut. Another person was hurt trying to hide under the desk.

Study of the Loma Prieta earthquake documented many instances of overturned files and bookshelves that were not properly braced and anchored. These building contents caused more injuries than non-structural elements, with the ratio of injuries from building contents to non-structural elements 3 to 1. People were hurt mostly by moving desks, filing cabinets, and furniture situated in the immediate vicinity of where those people were located (Cole et al. 1991). Therefore, building elements and contents play a clear role in saving or endangering occupants' lives (Durkin and Murakami 1988).

The 1979 El Centro earthquake study (Durkin, 1985) showed that 36% of office workers in the Imperial county services building, which sustained considerable non-structural damage, reported getting under their desks. The majority of them received minor injuries when their desks struck them or they bumped the desks while trying to get underneath. Of the 47 injuries that occurred, half happened to people engaged in evasive behavior - getting under desks or standing in doorways.

In other words, prior training and expectations play a significant role in the way that people respond to disasters; but these beliefs and expectations have to be reevaluated depending on the physical setting of each particular case, for they may prove to be dangerous. Thus, a significant number of respondents in Durkin's 1985 Mexico earthquake study reported that they chose to "stay where they were" once the shaking began, because they believed it was the right thing to do. As a result they were trapped in individual dorm rooms rather than trying to escape the building. Damage done to the General Hospital building by the earthquake made the drills and bomb-threats evacuation routes inoperative, and the nursing staff had to find alternate ways out, demonstrating the ad-hoc resourcefulness of disaster victims.

Durkin also asked the subjects in one of his studies (Durkin, 1987) whether and in what way the structural and nonstructural elements of the building as well as the building contents interacted to form pockets of space for survival. He indicated that the abovementioned elements clearly affected the victims' safety, although no specifics were offered. Finally, the same study attempted to tap into the fears of trapped victims. Responders indicated that their primary fear was of being crushed by the debris that would become unstable, for they were aware of the rubble over them being shifted and removed. Other fears included severity of injury, lack of oxygen, and lack of liquids and food.

Search and rescue and survival modeling of trapped victims in collapsed buildings.

Entrapment is the single most important factor associated with death or injury (Durkin and Murakami 1988). As Noji (2003) states, in the 1988 Armenia earthquake, death rates were 67 times higher and injury rates more than 11 times higher for people who were trapped than for those who were not.

Certain age groups are more vulnerable and have an increased risk for death and injury in disasters and others. Thus, people over 60 years of age have a death rate that can be five times higher than that of the rest of the population during earthquakes. Children between 5 and 9 years of age, women, and the chronically ill also have an elevated risk for injury and death (Glass et al. 1977). As Noji (2003) points out, limited mobility to flee from collapsing structures, inability to withstand trauma, and exacerbation of underlying disease are factors that may contribute to the vulnerability of these groups. He also stressed the effect certain social attitudes and habits of different communities may have on mortality distribution by age. For example, in some societies young children sleep close to their mothers and may be more easily protected by them.

Several studies examine the relationship between changes in response time and the saving of trapped victims (Kunkle 1989; Quon and Laube 1991; Pomonis et al. 1991; Coburn 1987). Kunkle claims that 80-90 % of entrapped victims who survive are recovered in the first 48 hours after the disaster impact, and that many more entrapped victims could survive with timely delivery of appropriate medical care. Quon and Laube developed a predictive model that suggests that a 10-20% reduction in response time would yield a 1-2.5% reduction in fatalities.

In the 1988 Armenia earthquake, 89% of those rescued alive from collapsed buildings were extricated during the first 24 hours (Noji et al. 1990). The probability of being extricated alive from the debris declined sharply over time, with no rescues after day 6. Noji (1991) points out that people have been rescued alive after 5, 10 and even 14 days of entrapment, but these constitute rare events.

Pomonis et al. (1991) stress the importance of a victim's health condition inside a collapsed building at a given time since the entrapment can be expressed as a function of time and the injury level sustained at the moment of entrapment. Other factors need to be accounted for as well: environmental factors like exposure, dehydration or starvation after a long period of time; weather conditions and the amount of air voids that are created within the rubble, the weight of the rubble above the victim; and the victim's pre-entrapment health condition. The study provides a number of empirical illustrations of the potential interplay between the mentioned factors. Thus, the collapse of the Juarez Hospital (a reinforced concrete frame building) in the 1985 Mexico earthquake trapped 740 people within the building. Search and rescue operations lasted more than 10 days, but only 179 were extricated alive. 76 percent died. On the day 1 the survival rate was 70% and this level was maintained until day 5. After that it dropped down to 20% by day 9. The implication is that 30% of trapped victims were killed instantly or injured too seriously to survive more than one day while the rest of the victims suffered relatively slight injury and survived for a while but began to die after day 5 because of bleeding, exposure, compression or some other reason.

An important finding shared by a large number of studies concerns rescue activities in the aftermath of disasters. In the period immediately following a catastrophic collapsed-structure event, many trapped victims will be rescued by the uninjured bystanders and surviving local emergency responders (Aguirre 1995; Noji 2003; Kunkle 1989; Durkin, 1987, 1988). For example, in southern Italy, in 1980, 90% of the survived trapped victims were extricated by untrained, uninjured survivors who used their bare hands and simple tools such as shovels and axes (Noji 2003). Following the 1976 Tangshan earthquake, about 200,000 to 300,000 entrapped people crawled out of the debris and went on to rescue others (Noji 2003). These volunteers became the backbone of the rescue teams. Michael Durkin (1987, 1988) specified that the primary rescue technique used by the SAR teams and volunteers was a human voice - the victims reacted to the rescuers calling out, and cried for help or made noise with available objects themselves.

Conclusion.

This literature review reveals a lack of information on a number of important research questions related to the entrapment of victims in the aftermath of disasters. These are: what are the factors responsible for the survival of building occupants? How does the location of the occupants, actions of the occupants, nonstructural elements and building contents, nature and time of entrapment, and method of rescue play a role in survival? Data on the circumstances of entrapment and location of voids can contribute to the development of effective SAR techniques and effective injury-prevention strategies.

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