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Classification and analysis of occupant behavior during earthquake shaking

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ABSTRACT: The primary goal of any earthquake hazard mitigation effort is to reduce human casualty. This paper emphasizes the importance of casualty reduction by studying hazards related to occupant behavior, building contents, interior design, and occupant decision making processes. A quantitative risk methodology, called Occupant Risk Analysis (ORA), was developed to assess hazards faced by building occupants during earthquake shaking. Validity of this method was tested using data obtained from the Loma Prieta earthquake of October 17, 1989.

1 INTRODUCTION

Sound structural design has been the corner-stone of earthquake safety in developed countries. For example, let us compare the ratio of death to injury caused by the Loma Prieta on October 17, 1989 (62/3,700) to that of a similar earthquake in northern Iran on June 20th, 1990 (40,000/60,000). It is apparent that significantly lower casualty results from the Loma Prieta event was primarily due to less structural collapse. Also, Loma Prieta earthquake occurred in mostly urban areas of a developed country with significant advances in earthquake hazard mitigation.

In addition to having sound structural design and building codes in California, better social preparedness and more efficient response management was mentioned as critical in reducing the negative effects of the Loma Prieta event (Baumgardner, 1990). As Riebsame (1989) indicates, it is important to assess "the knowledge and research needs in the behavioral, cultural, and economic aspects of hazards to complement efforts in the geosciences and engineering." Therefore, the range of factors involved in earthquake casualty and damage assessment and mitigation not only should address the engineering issues but also should consider the human aspects of a complex multi-factor earthquake environment.

1.1 *Earthquake casualty and human behavior*

Causes of earthquake casualties appear to be influenced by a large number of factors ranging from characteristics of ground motions and soil formations, typology of structures, to a multitude of social and behavioral factors. For a summary of research needs in this area, see Murakami and Durkin, 1988; Jones, et al 1990 and Tierney, 1990. Although structural hazards are the most significant causes of fatalities, recent data tend to support a notion of differential impact of earthquake hazards on death versus injuries (Alexander, 1985; Aroni and Durkin, 1985; Pollander and Rund, 1989; Ohta and Okada, 1989).

There is a growing body of evidence that non-structural elements and building contents can cause deaths and injuries and behavioral mitigation strategy can also be effective in reducing earthquake injuries. For example, the percentage of injuries related to the non-structural and building contents (e.g., glass, furniture, fixtures, appliances, chemical substances) appear to be higher than investigators had originally believed (Ohta and Ohashi, 1980; Ohashi and Ohta, 1984; Bourque et al, 1991). In a recent study from the Whittier Narrows earthquake (M5.9), Bourque et al (1991) reported that injuries occurred "primarily because objects fell from shelves or walls, because parts of buildings fell, because of how the injured person behaved during or immediately after the earthquake, or because the person fell during the earthquake."

As rural areas are more susceptible to casualty from building collapse, urban areas may be more vulnerable to injuries in multistory buildings and quick spread of secondary hazards such as fires. For instance, the following two studies contain data which indicate a correlation between the movement of objects inside structures and increased potential for occupant injury in urban areas. Naganoh (1991) reported that objects inside a 14-story building fell or thrown about significantly more in higher floors (ie. 7th floor and higher) than in the lower floors in a magnitude 7.4R in Sendai, Japan (see Figure 1). The household items studied appear to be of the kinds that can easily injure residents given the proximity of the projectiles. Also, for a list of fallen and broken items in residential buildings during the Loma Prieta event, see Table 1

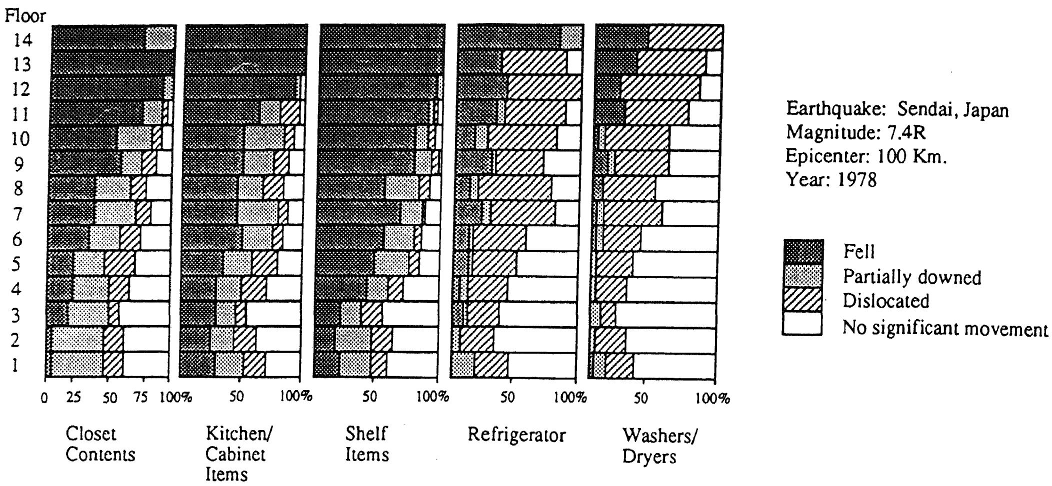

Figure 1. Effects of ground shaking on some objects inside a multi-story residential building.

adapted from Rahimi (1992). On the other hand, Noji and Malilay (1991) showed that, in the Mexico earthquake of 1985, the likelihood of receiving injury was 34.7 times larger in floors 7 and higher than in the lower floors. Therefore, non-structural elements and building contents pose a significant risk to occupants of building. This problem needs particular attention if one adds to this risk the hazards associated with improper occupant behavior and potential for entrapment.

Past discussions in this area point at a need to develop a methodology whereby occupant risks can be evaluated. A subjective assessment of the risks occupants face in an earthquake appears to be grossly insufficient given the multitude of factors involved. This paper attempts to explain a simple methodology whereby some of these hazard factors are taken into account simultaneously. Eventually, the goal of this approach is to produce an objective hazard assessment procedure within a broader framework of occupant risk assessment during earthquakes.

2 DEVELOPING A SURVEY/QUESTIONNAIRE

The first step in this process was to develop a survey/questionnaire which contained questions related to occupant behavior in earthquakes. In order to study the interactive nature of the hazard-producing factors, a retrospective questionnaire/survey was developed and administered to a small sample of 33 physically disabled residents after the Loma Prieta event. Also, an action sequence analysis was devised to assess the degree of hazard each occupant was exposed to during and immediately after the event.

2.1 *Questionnaire design*

The non-contextual aspects of the questionnaire (spacing, location of questions, font size, etc.) was based on the recommendations from Berdie and Anderson (1976). Forty four questions of closed and open-ended format were included in the survey. Clusters of questions provided detailed information on the respondents personal characteristics, judgements on hazardousness of the earthquake and building contents, and activities performed during and immediately after the shaking. The behavioral questions were designed to portray time chronology of occupants behavior in relation to the potential hazards present in their immediate environments (Keating, Loftus, and Manbar, 1983).

2.2 *Action sequencing*

The questions primarily relied on memory recall by "leading" the respondent through an action-sequence step for their observable behaviors (Friedman, 1987). The sequencing of the activities was made possible by anchoring the beginning and end of the action depiction list within the time frame of the occupant's perceived danger. We have added space in front of each question asking not only "how" they acted, but also "why" they did those actions. This section was particularly needed to assess the respondents' reasoning and decision-making processes behind their actions. In terms of administration of this questionnaire, single and short interviews were found to be effective and audio tape recording of the interviews were made as back-up for data collection and data extraction.

Table 1. A list of objects fallen/broken and their effects on occupant decisions.

Respondent	Fallen/Broken Items	Effects of Items on Actions
1	none	–
2	none	–
3	figurine from TV, potted plant	none
4	none	–
5	wine glasses, pottery items, potted plants	none
6	lamp shade, records, tapes	none
7	china clock, lamps, antique dish, vase, everything on book shelf	none
9	window panes, dry wall	none
10	none	–
11	copper enamel plate	conceived serious- made respondent move to hallway and outside, perceived duration of shaking as long
12	small picture frames	none
13	tin food, dishes	none
14	none	–
15	dishes, glassware, lamps, books, figurines	front door was jammed, required a hammer to open it, broken glass may have flattened the wheelchair tires
16	frames, book shelves, figurines	books blocked the main door, could not go anywhere
17	none	–
18	none	–
19	none	–
20	two frames	none
21	none	–
22	one dish	none
23	books, figurines, table lamp	moved backwards to avoid falling book
24	none	–
25	concrete pedestal, water cooler, books, paintings, sculptures, glass-ware, closet, sliding doors knocked open to a 30 degree angle	front door was blocked by plants and water cooler, debris on floor prevented easy maneuvering
26	heat lamp dislodged and was hanging by cord, most items from shelves and closet, table lamp, books, figurines, glass items	did not venture into kitchen due to broken glass and having air filled tires on wheel-chair
27	books, video tapes, records	none (went under doorway immediately, things could have been worse if he had waited a bit longer)
28	wall plaque	none
29	large computer terminal	crashing sound led to feeling of panic and closing of eyes
30	water dispenser, potted plant, tin food	none
31	lamp, books	none
32	none	–
33	chimney	none
34	paintings, magazine rack, pencil holder	none

3 AN OCCUPANT RISK ANALYSIS (ORA)

3.1 *Action classification*

The first step in our occupant risk analysis (ORA) is to break down the entire occupant action sequence into a manageable action classification. A list of independent action categories during an earthquake was generated (see Table 2). This is a generic list classifying only the type of actions that occupants may exhibit in earthquakes. The explanation for each action category shows the activity type, content, and potential hazards for occupants. For example, if the initial reaction to an earthquake was to enter into an involuntary passive mode (e.g. unable to comprehend the situation), the person was exposed to a higher risk. Since not all the action categories have the same importance in terms of hazard exposure, an Importance Multiplier has been assigned to each category. This Importance Multiplier is a rating (from 1 to 5) for the strength of the relationship (dependency) between the action item and hazard exposure. This rating was given by experts to each category, independent of the next item on the list. In Table 2, the strongest relationship exists for "decision

Table 2. A list of generic actions and their explanations for analysis of occupant hazard exposures.

Actions List (Importance Multiplier *)	Explanation
Initial Reaction (4)	Examines respondents immediate reaction to the earthquake. This could be physical, conscious, or involuntary action. It dictates whether respondents would be in a position to take any actions to avoid a hazardous situation. Regardless of the respondent's location, if the initial reaction is involuntary the individual is in a high risk-exposure situation.
Observation of Surroundings (3)	Respondents degree of hazard awareness and observation of surrounding items, which could range from thorough (that is, complete and objective), to none at all. This activity is not as closely linked to hazard exposure as the initial reaction, or the next activity of decision making.
Decision for Next Action (5)	Decision processes are examined as a planning tool for a series of actions. A typical decision is to move or stay-put, during the shaking. This is normally a conscious decision with a defined objective in mind. During the crucial moments of shaking, respondents cannot afford to make risky decisions that would place them in an injury-producing situation.
Protective Actions (4)	Occupants take a series of protective actions regardless of decisions made previously. These actions could range from being safe to risky with respect to potential hazards faced at that moment. Actions taken during the shaking period are significantly linked to occupant injury.
Interaction with Obstacles (4)	Encounter and interaction with obstacles during the shaking period, in an attempt to perform a task. Respondents may be involved in situations ranging from no obstacles/no difficulty to major difficulty.
Reaching Desired Goal (4)	Respondents reached their desired (stated) goal during the shaking period. Not reaching a desired goal may leave a person vulnerable to earthquake hazards.
Protective Actions After Shaking (3)	Respondents actions after the period of shaking may place them in a low or high risk situation. Potential hazards may be loose or dislocated objects, or dangers from aftershocks.
Interaction with Objects (2)	Unlike events during shaking, respondents have more time to interact with objects encountered in their paths. Range of difficulty for encounters and interactions may remain the same.
Reaching Desired Goal (2)	Indicates the degree by which respondents have accomplished what they wanted to do after the shaking stopped. Occupants may expose themselves to more hazards by setting low priority goals and performing unnecessary activity in a hazardous building immediately after an earthquake.

* Importance Multiplier is a measure of the dependence between each item in the list and the occupants exposure to potential hazards.

for next action" with a rating of five. In other words, in terms of overall exposure to hazards during an earthquake, it is extremely important to make a correct decision for action after the initial observation of the surrounding has been completed. This multiplier is a generic one and it is applied to each individual hazard rating within its category as described below.

3.2 *Hazard weighting factor*

The next step in ORA was to evaluate the actions performed by each respondent across all the generic categories listed in Table 2. In order to perform this evaluation quantitatively, a three-level Hazard Weighting Factor was constructed (Table 3). As described in Table 3, the Hazard Weighting Factor is -1 if the action performed by the person is a safe one. A factor of zero (neutral) is assigned to an action which is partially safe or does not contribute to a higher degree of hazard exposure. And, a factor of 1 is assigned to an action that significantly increases the potential for hazard exposure. Again, these factors were given by experts based on a subjective evaluation of all known potential hazard-producing circumstances within the built environment.

Then, the following procedure was carried out to evaluate the actions performed by each respondent. The initial and subsequent actions of each respondent was determined from our interview records. For example, let us assume that a person's reaction was to move a wheelchair under an overhead beam away from a glass window. This reaction was given a hazard weighting factor of -1, given that there was no indication of structural collapse in that section of the house. Similarly, hazard weighting factors were assigned to the remaining actions for this person. The nine numerical values were then multiplied by their corresponding importance multipliers. This step, for example, would result in a score of -4 for the first action item. Then, these values were summed which gave the final numerical score of hazard exposure for each individual. The theoretical range of minimum to maximum possible total scores for each respondent is from -31 to +31 (larger positive numbers denote increasing hazard exposures). The summed total scores for each of the 33 respondents were calculated and shown in Figure 2.

The total scores for our sample ranged from -28 to

Table 3. A hazard weighting factor chart for occupant hazard analysis.

Actions List	Hazard Weighting Factor		
	-1	0	1
Initial reaction	controlled motion	partially controlled	involuntary motion
Observation of surroundings	complete and objective	partially observant	none
Decision for next action	safe	somewhat safe	hazardous
Protective actions during shaking	safe	somewhat safe	hazardous
Interactions with obstacles	no obstacles/ no difficulty	some obstacles/ some difficulty	major difficulty
Reaching desired goal	reached	partially reached	not reached
Protective actions after shaking stopped	safe	somewhat safe	hazardous
Interactions with objects	no obstacles/ no difficulty	some obstacles/ some difficulty	major difficulty
Reaching desired goal	reached	partially reached	not reached

+28. A majority of respondents (26 persons) fell in the negative score region, indicating overall safe performance of their action sequences. From the seven respondents having positive scores, only two persons had scores significantly above 20 -- indication of exposure to a significant degree of hazard in the earthquake. The behavior of the person with the highest score is explained in detail.

Respondent #1, Score = +28

The respondent was in his chair watching television. The initial reaction for this person was an involuntary spasm, leaving him vulnerable to heavy objects falling from closet, television falling and blocking access, and potential falling of overhead ceiling fixtures. He was unable to control his wheelchair during the entire period of shaking until he received help from outside. During the initial seconds of the shaking, he was unable to observe his surroundings for potential hazards and did not recall making any judgment and decision making to alter his situation. He, therefore, stayed in the same body position and location throughout the entire shaking period. His major effort during the event was to control his spasms. He also tried to retrieve his mouth piece (a control device for wheelchair) that had shifted from its normal position. He was unsuccessful in reaching both of these goals.

For purpose of providing a contrast, the activities of the person with the lowest score is also elaborated.

Respondent # 20, Score = -28

The respondent was working at his computer terminal at the onset of shaking. All of his actions during the shaking period were based on conscious and controlled thought processes. His initial reaction was to pull away from the terminal where there were heavy book shelves and a number of breakable items. He then made a thorough observation of his surroundings and moved under the main overhead beam. Once the shaking stopped, he headed for the main door and remained outside for a while. His only possible hazardous activity was that he returned indoor to check the apartment for personal items while the potential for aftershocks existed.

4 CONCLUSIONS

Based on our analysis, it appears that a consistent application of this methodology can provide a quantitative profile of occupant behavior in relation to earthquake hazard exposures inside buildings. Using the quantitative three-level weighting factor, this method is capable of accurately categorizing the respondents action sequences in reference to a predetermined independent variable such as hazard exposure. Other studies may incorporate other independent variables such as age, gender, type of interior design, or prior earthquake experience. However, a disadvantage for this method is the degree of subjectivity by which some aspects of the actions are to be predefined. For example, in the list of generic actions, the last action item was classed as "reaching the desired goal." In our sample, some respondents were able to specifically mention whether they were successful in performing what they specifically wanted to do during the period of shaking. In other cases, however, this item needed to be later inferred by the expert evaluator from written or verbal explanations given by the respondents. This degree of subjectivity can be minimized by obtaining detailed information on all aspects of the environment within which the actions were taken place. For example, a person moving under a doorway may be assigned a safe score only if there is no door swinging violently by the shaking forces.

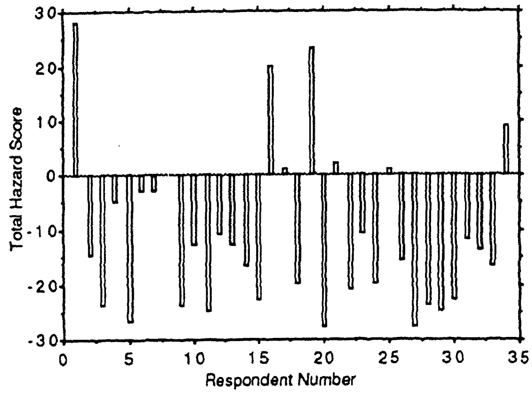

Figure 2. A bar graph indicating the total hazard exposures for a sample of 33 participants during the Loma Prieta Earthquake.

Nevertheless, this technique allows us to combine a subjective expert evaluation of human interactions (including environmental variables inside a room) with an objective assessment of hazard exposure. Further refinement of this technique would be able to incorporate into a single chart factors that are difficult to quantify such as position and location of dangerous objects, type and weight of objects, height and projectile of items in proximity to the occupant, and organization of household items in relation to the interior design of the room. It is hoped that the outlined procedure for quantification of occupant behavior would eventually result in a simple and effective evaluation tool. Such a tool would become helpful in analyzing a multitude of variables affecting safety of people inside buildings during earthquakes and would be used by interior designers and scientists involved in earthquake preparedness and education.

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REFERENCES

Alexander, D. 1985. Death and injury in earthquakes. *Disasters* 9(1): 57-60.

Aroni, S. & Durkin, M.E., 1985. Injuries and occupant behavior in earthquakes. *Joint U. S. and Romania Seminar on Building Research, Engineering, and Earthquakes*, September.

Baumgardner, E. 1990. The state role in earthquake response. *Networks* 5(1): 18-19.

Berdie P.J., & Anderson, K., 1976. *Questionnaires: Design and Use*. Metuchen, New Jersey: Scarecrow Publishers.

Bourque, L.B., Aneshensel, C.S. & Goltz, J.D., 1991. Injury and psychological distress following the Whittier Narrows and Loma Prieta Earthquakes. Presented at the *UCLA International Conference on the Impact of Natural Disasters*, Los Angeles, July.

Friedman, W.J., 1987. A follow-up to "scale effects in memory for the time of events": The earthquake study. *Memory and Cognition* 15(6): 518-520.

Jones, N.P., Krimgold, F., Noji, E.K., & Smith, G.S., 1990. Considerations in the epidemiology of earthquake injuries. Earthquake Spectra 6(3): 507-528.

Keating, J.P., Loftus, E.F., & Manbar, M., 1983. Emergency evacuation during fires: Psychological considerations. In *Advances in Applied Social Psychology II*, R. Kidd and M. Saks (Eds.). New York: Erlbaum.

Murakami, H.O. & Durkin, M.E., 1988. Studies of occupant behavior in earthquakes -- review and perspectives. Proceedings of the *Ninth World Conference on Earthquake Engineering*, Tokyo, Japan, VII-681 to VII-686.

Naganoh, M., 1991. Problems about action for earthquake disasters. Presented at the *3rd U.S./Japan Workshop on Urban Earthquake Hazard Reduction*. Honolulu: Hawaii, November, p. 78-79.

Noji, E.K. & J. Malilay, 1991. Medical response. Presented at the *3rd U.S./Japan Workshop on Urban Earthquake Hazard Reduction*. Honolulu: Hawaii, November, p.63-65.

Ohashi, H. & Y. Ohta, 1984. Importance of indoor and environmental performance against an earthquake for mitigating casualties. *Proceedings of the 8th World Conference on Earthquake Engineering*. Englewood Cliffs: New Jersey, Prentice Hall, 423-430.

Ohta, Y. & H. Ohashi, 1980. A field survey on human response during and after an earthquake. *Proceedings of the 7th World Conference on Earthquake Engineering*. Volume 9: 345-352.

Ohta, Y. & S. Okada, 1989. An assessment of time-dependent earthquake effects on a household in terms of living standards. *Journal of Natural Disaster Science* 11(2): 51-68.

Pollander, G.S. & D.A. Rund, 1989. Analysis of medical needs in disasters caused by earthquakes: The need for a uniform injury reporting scheme. *Disasters* 13(4): 365-369.

Rahimi, M., 1992. An examination of behaviors and hazards faced by physically disabled people during the Loma Prieta earthquake of October 17, 1989. *Natural Hazards*. (In press)

Riebsame, W.E., 1989. Reducing hazards during the 1990s. *Natural Hazards* 1(4): 387-389.

Tierney, K.J., 1990. Developing multivariate models for earthquake casualty estimation. Presented at the *Workshop on Modeling Earthquake Casualties for Planning and Response*, Pacific Grove, California, December 4-6.