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FACTOR ANALYSIS OF HUMAN ENTRAPMENT AND CASUALTY OCCURRENCE DUE TO DWELLING COLLAPSES IN THE 1995 HANSHIN-AWAJI EARTHQUAKE

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SUMMARY

In the 1995 Hanshin-Awaji earthquake in Japan, approximately 5500 human lives were lost loss by destruction of dwellings and various structures. Authors conducted questionnaire survey in Higashinada ward of Kobe city to examine how human casualty and entrapment are affected by dwelling damage levels, environmental factors and personal attributes and responses. Ratio of injury are found to increase as dwelling damage reach from heavy damage to total collapse, and in case of location on the first floor, all furniture falling, and age over 70s. As for entrapment, total collapse of dwellings, serious or grave injury, location on the first floor, and all furniture falling seems to increase the risk.

INTRODUCTION

The 1995 Hanshin-Awaji earthquake (Mj=7.3) occurred early morning at 5h46m of January 17 and caused 6433 human loss, of which approximately 5500 were directly caused by destruction of dwellings and various structures (Miyano et al. [1], Murakami [2]). The authors made questionnaire survey in Higashinada ward of Kobe city in 2000 to investigate relations of dwelling damage conditions, human casualty and entrapment conditions (Takeda et al. [3]). A simplified schematic model suggests entrapment z as a function of dwelling damage level x and human casualty y (Fig. 1). Considering such a model, this study first examines how to define conditions and levels of the entrapment, and tries to clarify how dwelling damage level, environmental conditions and personal attributes affect casualty and entrapment risk by applying discriminant analysis with Hayashi's Quantification Theory II. The results can be applied to mitigation of human casualty occurrence, SAR operation strategies and disaster planning.

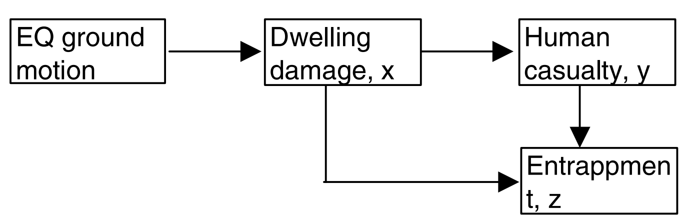

Fig. 1 Schematic model for entrapment

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QUESTIONNAIRE DATA IN HIGASHINADA WARD

Survey outline

The questionnaire survey was conducted in Higashinada ward as indicated in Table 1. Six neighborhoods of different damage levels were selected comparing dwelling damage and casualty distribution. Two types of the questionnaire formats were prepared. Format A is for each household to answer number of family members, type and story of a dwelling, year built, damage levels of a dwelling and furniture and contents damage, current community disaster preparedness and recovery level. Format B is for each family member to answer location at the time of the earthquake occurrence, immediate response, casualty and entrapment conditions. The data of questionnaire forms A and B were processed to construct relational database with family ID number. It means that data of household and dwelling conditions can be referred when processing family member outcomes of casualty and entrapment. The original questionnaire formats were developed by Ohta et al. [4] to make extensive questionnaire survey in Hokudan town near the earthquake epicenter in October 1995.

Table 1 Outline of the questionnaire survey at Higashinada ward

Survey area	Higashinada ward, Kobe city
Survey date	October, 2000
Questionnaire A	608 distributed
for each household	474 collected (77.9%)
Questionnaire B	1,597 distributed
for each family member	1,145 collected (71.7%)
Higashinada Ward	
population	187,599
number of household	62,777
JMA intensity	6+ and 7
heavily damaged dwellings (buildings)	11,171
human loss	1,332
number of fire occurrence	379

Types of dwellings and damage conditions

Figures 2 and 3 indicate distribution of structural types and story of dwellings respectively, as derived from form A. Wooden dwellings take 80 % of the samples and majority of 83% are two story dwellings. Figure 4 shows damage levels of dwellings. Total collapse shares 17%, while heavy damage beyond repair takes 30%. As for the wooden dwellings, damage distribution is most severe among the different structural types, and that total collapse takes 20.9%, heavy damage is 36.2%, partial damage is 23.6%, light damage takes 16.6% and no damage is 2.4%.

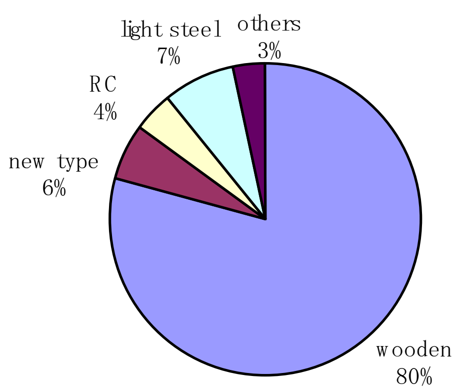


Fig. 2 Structural type of dwellings.

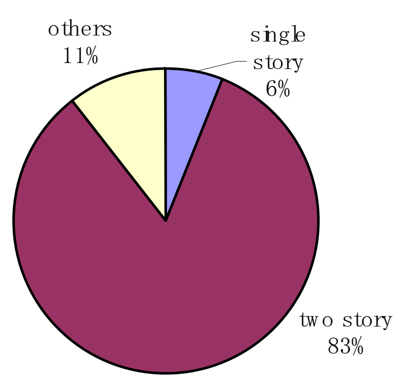


Fig. 3 Story of dwellings.

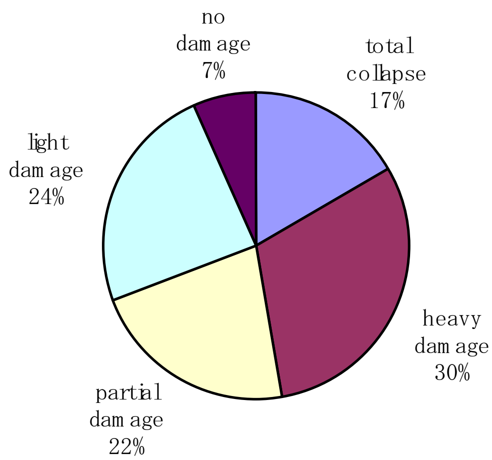


Fig. 4 Damage levels of dwellings.

DEFINITION OF ENTRAPMENT

Disabilities due to physical confinement and spatial disorder
In the questionnaire format B, there are two questions asking conditions of behavioral disability at the end of earthquake shaking. Those are:

Question 2-5: Were you in such conditions of behavioral disability due to physical confinement over lower limbs, upper body, or whole body?
1. No disability 2. Moderate disability 3. Almost impossible to move

Question 2-6: Were you in such conditions of behavioral disability due to indoor spatial disorder caused by fallen furniture, contents, any architectural elements and/or displaced structural elements?
1. No disability 2. Moderate disability 3. Almost impossible to move

Table 2 indicates a cross table between the two questions of disability due to physical confinement and that due to indoor spatial disorder. Here, we define the cases which correspond to category 3 almost impossible to the question item of physical confinement as "Physical Entrapment". Also, we define the cases which correspond to category 3 almost impossible to the question of indoor spatial disorder, except for physical entrapment, as "Spatial Entrapment". In the table 2, physical entrapment shares 91 cases (8.3%) out of 1090 samples, while spatial entrapment shares 299+28=327 cases (30.0%) out of the same 1090 samples.

Table 2 Relation of two disability conditions

		Q2-6: Disability due to indoor spatial disorder			
		1 No disability	2 Moderate disability	3 Almost impossible	Total
Q2-5: Disability due to physical confinement	1 No disability	108	516	299	923
	2 Moderate disability	4	44	28	76
	3 Almost impossible	0	10	81	91
	Total	112	570	408	1090

Physical Entrapment

Spatial Entrapment

Conditions of evacuation

In the questionnaire form B, there is a question asking either one could evacuate outside alone or with assistance by family or outside groups.

Question 3-1 How could you evacuate outside of the dwelling or were you rescued by others?

1. I was outside and did not need to evacuate.
2. I evacuated alone.
3. I evacuated with family assistance.
4. I was rescued by other people (neighbors, firemen, or others)

The Table 3 compares relation of the question 3-1 of evacuation and entrapment conditions defined above. While 391 cases (41.0%) out of 954 samples applies either physical or spatial entrapments, 217 cases (22.7%) out of the same samples apply to evacuation with assistance or rescue by family or other group of people. Ratio of self evacuation decreases from 88.1% (=496/563) of no entrapment, to 72.1% (=217/301) of spatial entrapment, and then to 26.7% (24/90) of physical entrapment. Conditions of evacuation depends not only upon physical and spatial conditions immediately after the earthquake shaking, but also upon location of family members close by. That is, either one was alone at home or with family members. There can be cases of no serious entrapment though evacuation with assistance by family or others, in which family members might take one's hands in the darkness to evacuate. On the other hand, in case of self evacuation under the conditions of physical or spatial entrapment, family members or neighbors might not be close enough to assist, they might have great difficulty to get out of the entrapment conditions.

Table 3 Cross table between evacuation conditions and entrapment levels

		Conditions of entrapment			
		Physical entrapment	Spatial entrapment	No entrapment	Total
Q3-1 Conditions of evacuation	3 &4 with assistance or rescue by family & others	66	84	67	217
	2 Self evacuation	24	217	496	737
	Total	90	301	563	954

FACTORS AFFECTING CASUALTY AND ENTRAPMENT

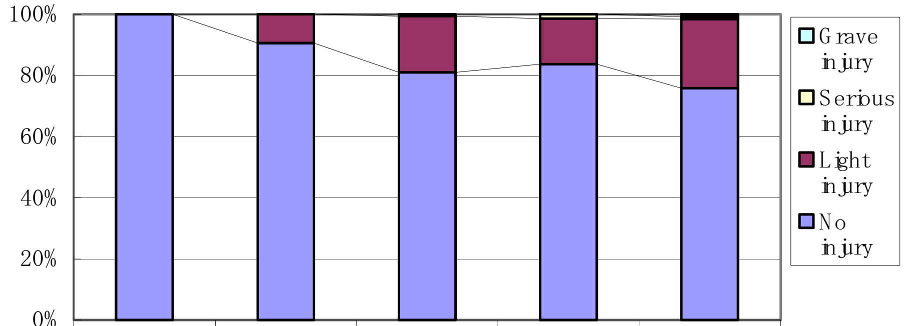
Human casualty vs. dwelling damage and other conditions

Distribution of human casualty with changing levels of dwelling damage is shown in Fig. 5. Percentage of light injury increases from light damage to partial damage, and seems rather stable along heavy damage to total collapse. On the other hand, percentage of serious and grave injury increases in the cases of dwellings heavily damaged and those totally collapsed.

Entrapment vs. dwelling damage and other conditions

Figure 6 compares ratio of disabilities along dwelling damage levels. The disability by spatial disorder constantly increases in accordance to the dwelling damage and reaches to 70% in total collapse. The disability by physical confinement especially increases and reaches to 28% in the cases of totally collapsed dwellings.

Location of people at the time of earthquake occurrence affect entrapment risk especially in the cases of totally collapsed dwellings. It is because two story wooden houses tended to collapse and be flatten in the ground story level leaving the second story far less destroyed. Figure 7 indicates such clear difference of physical confinement risk between the 1st and 2nd stories. Comparing ratios of disability due to indoor spatial disorder between 1st and 2nd stories, the percentage of spatial disability seems larger for the 1st story rather than the 2nd story.



	No damage	Light damage	Partial damage	Heavy damage	Total collapse
Grave injury	0.0%	0.0%	0.0%	0.0%	0.8%
Serious injury	0.0%	0.0%	0.7%	1.5%	0.8%
Light injury	0.0%	9.4%	18.4%	14.8%	22.6%
No injury	100.0%	90.6%	81.0%	83.7%	75.8%

Fig. 5 Ratio of human casualty vs. dwelling damage levels.

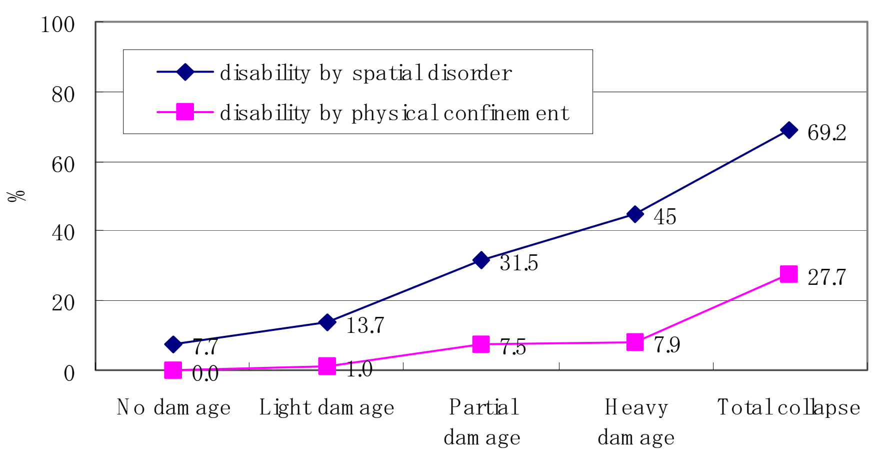


Fig. 6 Ratio of disability due to spatial disorder (category 3 for Q2-6) and that due to physical confinement (category 3 for Q2-5) vs. dwelling damage levels.

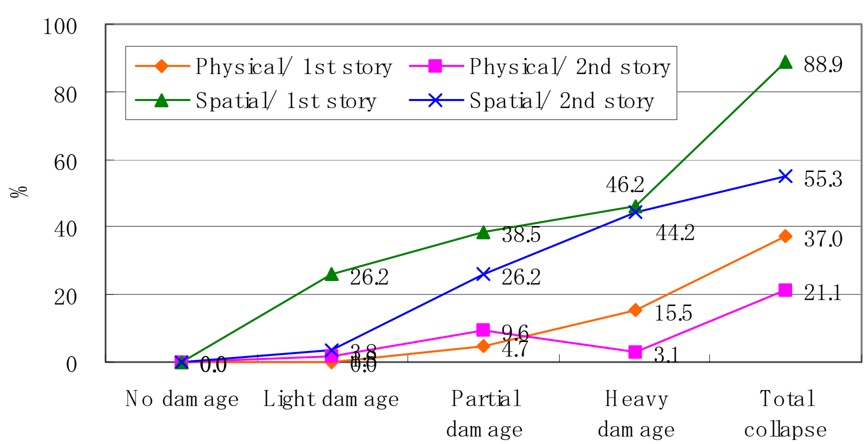


Fig. 7 Disability due to spatial disorder (category 3 for Q2-6) and that due to physical confinement (category 3 for Q2-5) vs. location at the time of earthquake and

dwelling damage levels.

DISCRIMINANT ANALYSIS OF CASUALTY AND ENTRAPMENT

Data for analysis

In order to examine how human casualty and entrapment were affected by structural dwelling damage levels, dwelling content damage such as falling furniture, personal location and attributes, we applied discriminate analysis with Hayashi's Quantification Theory II, because independent variables are mostly categorical data.

Out of the 1145 individual cases originally collected, 605 cases from wooden dwellings and with effective response to behavioral disability Questions 2-5 and 2-6 in the form B were selected for the analysis. Table 4 indicates a list of dependent and independent variables and their categories.

Table 4 Items and categories of independent and dependent variables

	1	2	3	4	5
Human casualty	No injury	Light injury	Heavy & grave		
Dwelling damage level	No damage	Light damage	Partial damage	Heavy damage	Total collapse
Falling furniture	None	Some	Many	All	
Age	under 20	20s -60s	over 70s		
Sex	male	female			
Location at earthquake	Sleeping at 1st floor	Sitting up 1st floor	Sleeping at 2nd floor	Sitting up at 2nd floor	
Entrapment	No	Spatial	Physical		

Analysis of human casualty

Human casualty (injury) is regarded as an objective variable for discriminant analysis taking 5 independent variables indicated as in Table 5. No injury, light injury and serious injury are 495 (%), 95 cases (%), and 15 cases (%) respectively. Correlation ratio, which is as low as 0.105, suggests that it is very difficult to discriminate occurrence of injury. Relatively speaking, falling furniture, age and dwelling damage tend to affect the chances of injury. As shown in Fig. 8, all furniture falling, age over 70s, and heavy damage and total collapse of dwellings seem to increase the risk of injury.

Table 5 Partial correlation coefficients of independent variables with injury

Independent var.	1st axis
Dwelling damage	0.112
Falling furniture	0.158
Sex	0.085
Location	0.187
Age	0.134

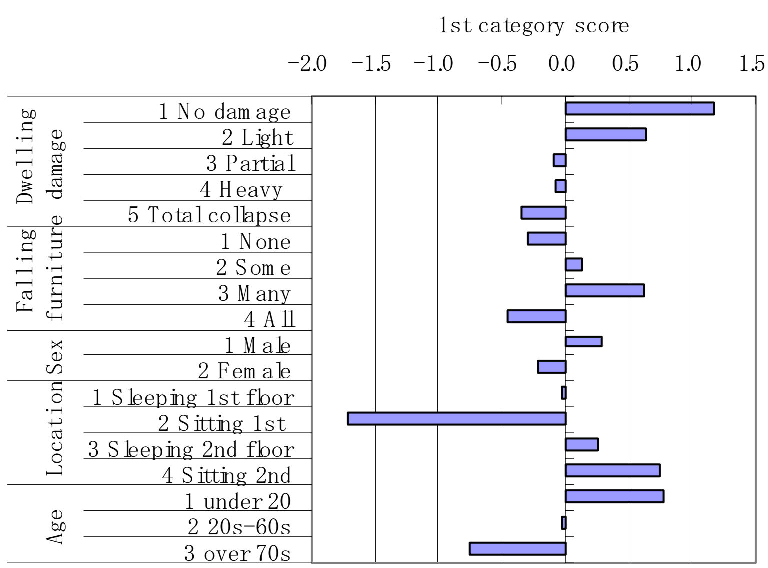


Fig. 8 Category scores for discrimination of human injury.

Analysis of entrapment
Objective variable of entrapment is examined by discriminant analysis taking 6 independent variables as indicated in Table 6. No entrapment, spatial entrapment and physical entrapment are 349 cases (%), 192 cases (%), and 64 cases (%) respectively. Correlation ratio of 0.270 is very low, suggesting entrapment also occurs in a probabilistic manner and it is difficult to discriminate entrapment and non entrapment cases. According to Table 6, dwelling damage level, injury and location are the factors most affecting. As depicted in Fig. 9, total collapse of dwellings, light or heavy injury, and location at the 1st floor are the categories resulting higher risk of entrapment.

Table 6 Partial correlation coefficients of independent variables with entrapment

Independent var.	1st axis
Dwelling damage	0.297
Falling furniture	0.125
Sex	0.015
Location	0.144
Age	0.112
Injury	0.277

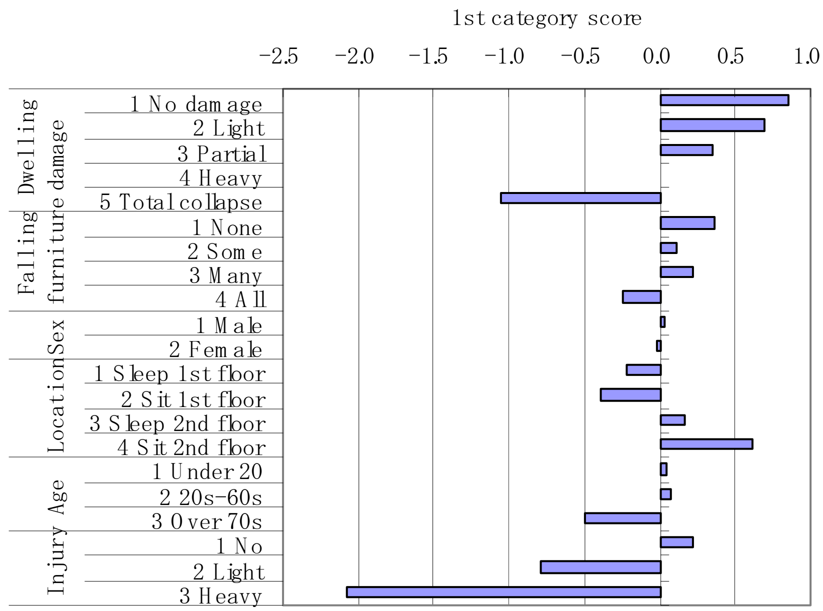


Fig. 9 Category scores for discrimination of human entrapment.

CONCLUDING REMARKS

Questionnaire survey was conducted in Higashinada ward of Kobe city severely damaged in the 1995 Hanshin-Awaji earthquake to investigate how human injury and entrapment conditions were affected by dwelling damage levels, environmental conditions and other personal attributes. According to the results of household survey forms, 80% were wooden dwellings, 83% were two story. As for the dwelling damage levels of whole samples, total collapse shares 17% and heavy damage shares 30%, while wooden dwellings suffered higher damage ratios.

Entrapment was defined using two questions of family member format regarding disability due to physical confinement and that due to indoor spatial disorder. Physical entrapment shares 8.3% and spatial entrapment shares 30.0%. Entrapment conditions do not always agree with conditions of evacuation, though self evacuation decreases from no entrapment cases (88.1%), to spatial entrapment cases (72.1%) and then to physical entrapment cases (26.7%).

Human casualty and entrapment are found to increase while dwelling damage becomes severer. Especially, serious injury and disability by physical confinement increase significantly from heavy damage to total collapse. Spatial disability and physical disability was found greater for the 1st story level in case of heavy damage and total collapse dwelling damage.

Discriminant analysis with Hayashi's Quantification Theory II was applied taking human casualty and entrapment as objective variables for the cases located in wooden dwellings. Reliability of estimation is low in both cases suggesting human injury and entrapment is probabilistic phenomena and is difficult to discriminate injury and non-injury cases or entrapment and non-entrapment cases. However, 1st category scores suggest how they affect risks of injury and entrapment. As for injury, location on the first floor, all furniture falling, age over 70s and total collapse of dwellings are the factors tending to increase the risk. As for entrapment, total collapse of dwellings, serious or grave injury, location on the first floor, and all furniture falling seems to increase entrapment risks.

As for the future tasks, questionnaire results of the Hokudan town can be analyzed in view of injury and entrapment risks in the same manner and be compared with the result above to find out how rural or urban environmental and community factors affect the outcomes. Numerical expression can be developed to estimate entrapment level as a function of dwelling damage and injury levels for further generalized understanding of the problems, for finding out effective measures to reduce human casualty and entrapment, and for finding out effective strategies for search and rescue efforts.

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