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STUDY ON SEARCH AND RESCUE OPERATIONSIN THE 1995 HANSHIN-AWAJI EARTHQUAKE– ANALYSIS OF LABOR WORK IN RELATION WITH BUILDING TYPES

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SUMMARY

In the 1995 Hanshin-Awaji earthquake, 5,500 human lives were lost mostly due to collapse of residential buildings. This study aims to review search and rescue (SAR) records of the fire departments in the severely damaged municipalities and to analyze labor work and time dependent survival rates in relation with building types. Search and rescue records were collected from 6 fire stations in Kobe City, and fire departments of Ashiya, Nishinomiya, Takarazuka, and Amagasaki cities and Tsuna region of Awaji Island. Approximately 1,900 cases of SAR operation contain date and time of action, time spent, address, building type, number of people rescued alive and dead, number of personnel, and available tools and equipment. The amount of time spent for one case of SAR was found to depend upon structural type, number of people rescued, number of rescue personnel and days after the earthquake. Survival rates along hours and days after the earthquake occurrence depict that collapsed multi-story RC or steel buildings tend to keep entrapped people alive longer than collapsed wooden buildings.

INTRODUCTION

In the 1995 Hanshin-Awaji earthquake, National Police Agency reported that 5,502 human lives were lost and 87.9% of death caused by collapse of dwellings, 10.4% of those caused by fire (as of March 31, 1995). National Fire Agency reported total damage statistics as 100,302 buildings housing 183,000 households heavily damaged, 108,741 buildings partially collapsed, 6,308 people killed and 43,177 people injured (as of Dec. 27, 1996). The difference of the two fatality numbers indicates addition of earthquake-related illnesses and

accidents. Murakami (1996) reported distribution of human casualties in relation to building damage. This study aims to review search and rescue (SAR) records of the fire departments in the severely damaged municipalities and to analyze labor work and time required to complete SAR tasks in relation with building types.

ESTIMATION OF SERCH AND RESCUE PARTICIPANTS

There is almost no report regarding how many people were trapped under the collapsed buildings requiring outside rescue except for limited case studies. Figure 1 indicates a tentative estimation of by whom trapped people were rescued in Kobe City. Let us assume that 3,855 people killed and 14,679 people injured were in trapped conditions that requiring search and rescue operations. Based on the reports by Kobe City fire

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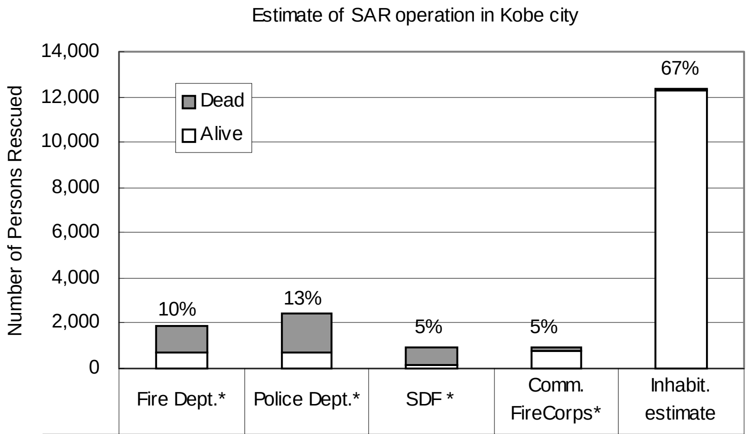
department, by Hyogo Prefecture Police and by Self Defense Forces, their contribution is thereby indicated in the Figure. The remaining numbers of those killed and those alive (injured) are regarded as contribution by local inhabitants such as neighbors, families and friends. This estimation suggests almost 67% of the rescue were conducted by local inhabitants, whereas the fire department performed SAR operations requiring professional skills.

If we change the assumption that 3,855 people killed and half of 14,679 people injured were trapped, share of inhabitants drops to 45%, and shares of fire department, police department, SDF, and community fire corps become 17%, 22%, 8% and 9% respectively.



	Fire Dept.*	Police Dept.*	SDF *	Comm. FireCorps*	Inhabit. estimate
Dead	1159	1729	774	139	54
Alive	733	701	133	819	12293

*: Information provided by Kobe City Fire Department (1995). Police Agency and Self Defense Forces conducted SAR in cooperation with Fire Departments. Hyogo Prefectural Police (1996) reported to have rescued 2385 people alive within Kobe city, though it mentioned no report of dead rescue.

Figure 1: Estimation of search and rescue operations in Kobe city

SERCH AND RESCUE RECORDS BY FIRE DEPARTMENTS

Definition of One Case of Search and Rescue

Search and rescue records were collected from 6 fire stations in Kobe City, and fire departments of Ashiya, Nishinomiya, Takarazuka, and Amagasaki cities and Tsuna region of Awaji Island. Approximately 1,900 cases of SAR operation contain date and time of action, time spent, address, building type, number of people rescued alive and dead, number of personnel, and available tools and equipment.

In this study, one case of SAR operation is defined as a series of SAR work conducted in one site of building within a single day rescuing single or plural number of people either dead or alive. If another rescue team arriving at the same site conducted SAR operation in the same building as one rescue team conducted SAR operation in other dates, each operation is regarded as an independent case of operation. If the search is conducted and no one was found, the operation is not counted as a case of SAR in this study.

Time spent for one case of SAR is the period since the arrival of rescue team on site until the time the last person rescued at the same site of rescue work. Number of rescue personnel participating one SAR event counts the number of personnel in the fire department or fire brigade. Therefore, the number of local residents such as neighbors, families and friends are not included in the number of personnel. It is very important to understand that data are often incomplete and different in accuracy, because each fire station after the earthquake faced a conflicting burden performing SAR operation and fighting spreading fires.

Building Types

The building types and the damage levels are important parameters, which affect amount of labor needed for SAR work and possibility of survival under the debris. Three types of the buildings or mostly dwellings categorized are the wooden detached dwellings, wooden apartments, and non-wooden buildings. If the building type category is not clearly indicated, name of buildings and apartments are interpreted for estimation. Table 1 indicates crosstable of SAR data by fire departments and three building types. The damage level indicated in the SAR records are often “collapsed” or “heavily damaged”. It is difficult to interpret damage level from the records.

Table 1: Number of SAR cases by building types

	Building Structures				
	Wooden Detached	Wooden Apartment	Non-wooden	Unknown	Total
Takarazuka	25	4	4	4	37
Nishinomiya	253	7	12	7	279
Ashiya	43	4	16	4	67
Higashinada Fire Station					
Higashinada FS alone	42	5	4	1	52
Tokyo Metro Fire Assistanc	17	0	23	4	44
Other City Fire Assistance	9	25	28	144	206
Nada Fire Station	27	27	11	203	268
Ikuta Fire Station	33	14	46	12	105
Fukiai Fire Station	0	7	6	3	16
Suma Fire Station	75	39	10	4	128
Hokudan Town	113	0	1	0	114
Total	637	132	161	386	1316

Time Dependent Survival Rate

It is well known that survival rate of those rescued decreases along days after the earthquake and the same tendency is found in case of our data. Figure 2 indicates survival rates for the three building types. RC or steel buildings show the highest survival rate on the first and the second day, probably because people trapped in damaged doors and elevators were rescued in the early stage. Shiono et al. (1992) introduced fade away analysis of trapped people in the collapsed RC hospital in the Mexico earthquake and indicated that collapsed RC or steel buildings tend to maintain secure space for people between beams and floors.

Coburn et al. (1992) reported survival rate reduction for different building types from world-wide earthquake disaster statistics as shown in Figure 3. Comparing Figures 2 and 3, wooden dwellings and apartments in Hanshin area show similar tendency as weak stone masonry in Italy.

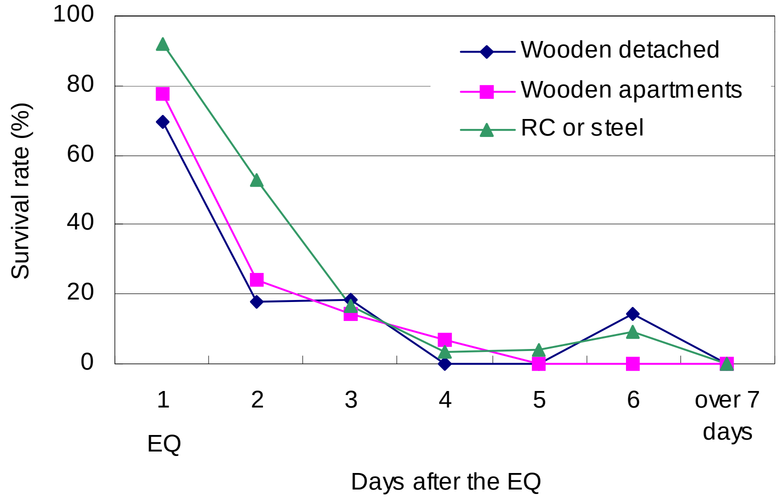


Figure 2: Survival rate along days after the earthquake for three types of buildings.

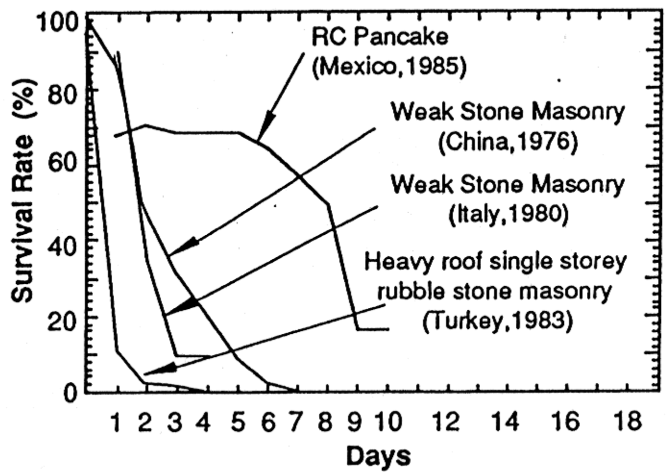


Figure 3: Time dependent decrease of survival rate reported by Coburn et al. (1992).

ANALYSIS OF LABOR WORK WITH BUILDING TYPES

Hypothesis of Unit Labor Work

In order to quantify the amount of labor work to perform search and rescue operation of one person trapped, the following relation is examined:

$$X = P\,H/V \tag{1}$$

Whereas

X: unit labor work

P: number of personnel participated in the rescue (persons)

H: amount of time spent (minutes)

V: number of victims rescued

Assumption here is that increase of rescue personnel results in decrease of time spent for rescue and that increase in number of victims rescued results in increase of time spent for rescue. Out of the 1316 rescue records, 549 cases (403 wooden detached dwellings, 65 wooden multi family apartments, and 81 non-wooden buildings) have complete dataset of the time spent for SAR, number of people rescued, and number of personnel participated and is used to examine the above relations.

Equation (1) is revised as;

$$H = a (V-1) + b \tag{2}$$

Where as b: base time to rescue the first victim from site

a: additional time for rescue of the second, third, etc victims.

Linear regression is obtained for the three building types (Table 2). Parameter a is always plus and that means increase of victim results in increase of number of victims rescued. Parameter a is approximately 1/3 through 1/4 of the parameter b (base time). Both parameters b and a indicate tendency of non-wooden > wooden apartments > wooden detached.

Next, equation (1) is revised as;

$$\log H = c \log P + d \tag{3}$$

Linear regression is obtained for the tree types of buildings (Table 3). Parameter c is plus for wooden detached and RC or steel buildings, which means that increase of personnel results in increase of time spent. Parameter c is minus for wooden apartments suggesting the reverse relation, though correlation coefficient is very low. This means that addition of rescue personnel does not simply reduce the time required for rescue. Rather, number of personnel is affected by how difficult and complex the collapsed building is.

Table 2: Slope a and constant b of regression equation (2)

	Wooden detached	Wooden apartment	RC or steel
slope, a	19.2	25.9	49.0
constant, b	83.4	93.9	184.2
Correlation Coefficient	0.67	0.72	0.61

Table 3: Slope c and constant d of regression equation (3)

	Wooden detached	Wooden apartment	RC or steel
slope, c	0.24	-0.16	0.74
constant, d	1.75	2.12	1.38
Correlation Coefficient	0.84	0.27	0.64

Multiple Regression Analysis to estimate SAR time

As mentioned in the previous section, it is difficult to define unit labor work (hour*person/personnel) and to measure the difficulty of search and rescue operations. Figure 4 depicts cumulative distribution of time for rescue work for three building types. It is obvious that RC or steel buildings tend to make rescue work more time consuming and laborious compared to wooden buildings. Wooden detached dwelling and wooden apartments show similar tendency. The distribution of time range is very large spreading approximately from 15 minutes to almost 400 minutes.

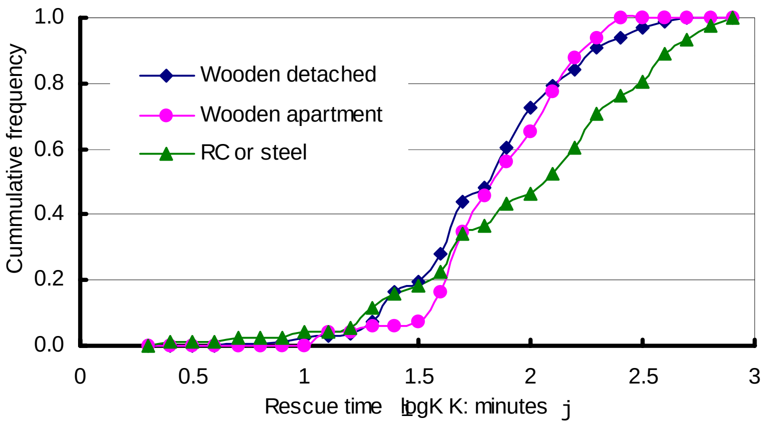


Figure 4: Cumulative distribution of SAR time spent for three building types

Multi regression analysis is performed to estimate the objective variable of time spent for one site of SAR. Because independent variables contains not only quantitative, but also qualitative variables, Hayashi's Quantification theory I is applied. Assumed equation is as follows.

$$Y = C1 + C2 + C3 + C4 + C0 \tag{4}$$

where

Y: time (minutes) spent for one case of search and rescue.

C1: Structural type

C2: Number of people rescued

C3: Number of rescue personnel

C4: Days after the earthquake

C0: Constant

Table 4 indicates frequency of each independent variable categories and mean value of time spent for one SAR site. Category scores and category ranges are the result of analysis. The most significant independent variable is type of building and the difference between non-wooden type and wooden detached dwelling reaches 80.65 minutes. The second significant variable is the number of people rescued and "more than 3 people rescued" give 78 minutes longer time than "one person rescued". The number of personnel tends to increase the time for rescue, probably because two or more rescue teams were dispatched to very difficult SAR sites such as multi-story RC or Steel structures totally collapsed. Correlation coefficient of multi variegate regression is very low of

0.36. This suggests that it is important to introduce additional independent variables such as SAR difficulty index, damage level of buildings, and use of SAR equipment.

Table 4: Category score and category range obtained for the empirical equation.

Item	Category	Frequency	Mean (minutes)	Category score	Category range
Structural type	Wooden detached	403	114.73	-6.73	
	Wooden apartment	65	108.42	-26.16	
	RC or steel	81	200.42	54.49	80.65
Number of people rescued	one person	368	117.45	-9.31	
	two pesons	119	115.18	-7.15	
	more than 3	62	203.02	68.96	78.26
Number of personnel	1-3 personnel	110	96.30	-25.41	
	4-6 personnel	230	111.69	-16.50	
	7-9 personnel	51	149.47	21.10	
	over 10	158	162.09	34.91	60.32
Days since the eq	day 1	305	112.69	-4.85	
	day 2	97	147.33	3.01	
	day 3, later	147	141.86	8.07	12.92
Constant				126.62	

CONCLUSIONS

In the Hanshin Awaji earthquake, fire departments played a crucial role in search and rescue activities of people trapped under collapsed and severely damaged buildings and dwellings. This study examined how much time is needed to conduct SAR of one site and how survival rate decrease along days after the earthquake.

The findings are as follows;

(1) Amount of time needed to perform one site of SAR is proportional to number of people rescued, while it does not agree with number of rescue personnel.

(2) Multiple regression analysis was conducted to estimate amount of time required for rescue using Hayashi's Quantification Theory. Structural type, number of people trapped, and number of personnel are important parameters. Collapsed reinforced concrete (RC) or steel buildings required twice or more labor than collapsed wooden dwellings and wooden tenement houses.

(3) Survival rates along hours and days after the earthquake occurrence depict that collapsed multi-story RC or steel buildings tend to keep entrapped people alive longer than collapsed wooden buildings, which agrees with the previous study of Coburn et al. (1992).

(4) In order to improve reliability of estimation, additional factors should be found and included.

(5) As for the survival rate along days after the earthquake, deterioration process of human health under trapped conditions should be further examined to understand the phenomena.

These results will give SAR models fundamental parameters regarding demands for search and rescue work and effectiveness of response resources such as personnel and equipment dispensation. They will also provide guidelines to develop emergency response strategies and management systems for maximizing number of people rescued alive. It is important to clarify roles of professional SAR teams and local community organizations. We hope this study will be useful for improving long-term measures and preparedness to mitigate human casualties caused by structural collapses in future earthquakes in any seismic prone countries.

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