HUMAN CASUALTY ESTIMATION DUE TO URBAN EARTHQUAKE

Hengjian LU[1], Masayuki KOHIYAMA[2], Norio MAKI[3], Satoshi TANAKA[4] And Haruo HAYASHI[5]

SUMMARY

Since the 1995 Hanshin-Awaji earthquake disaster, damage estimation analyses for potential earthquake hazards have been carried out by many administrative organizations in Japan. One of the key issues in these analyses is to estimate the number and spatial distribution of human casualties as accurately as possible. We focused on Nishinomiya City, which was one of the most heavily damaged cities in the Hanshin-Awaji earthquake disaster, and constructed a built environment database of Nishinomiya City. Using this database, constructions of the age and sex of individuals and the spatial distribution of the dead, as well as the relationships between the ages of houses and ages of the dead were investigated. This paper provides a technique of constructing a relational geographic information system (GIS) database with several different types of data. Using this GIS database and through Weibull analysis, we arrived at two conclusions regarding the distribution of the age and sex of the dead caused by the earthquake. (1) The earthquake mortality rate distribution of the under-50-year-old age group exhibits a constant occurrence pattern, and that of the over-50-year-old age group exhibits an increasing occurrence pattern. (2) The high ratio of the aged living in relatively old houses is one of the reasons resulting in the higher mortality rate of the aged than that of the young.

INTRODUCTION

The causes of human casualty in earthquakes are rather complicated. It is considered that the casualty rate is not only related to seismic intensity and soil condition, but also to the age and sex of individuals and the characteristics of the area's environment. In order to estimate the quantity and spatial distribution of human casualties as accurately as possible, it is necessary to clarify the constructions of age and sex of the individuals and the relationships between the characteristics of the area's environment and the spatial distribution of the dead caused by earthquake.

We examined Nishinomiya City and constructed a GIS-based database to identify the location and number of human casualties caused by damaged building due to the earthquake. This relational built environment database stores building data and human casualty data, such as age and sex of individuals, causes of death, mortality location, building age, building location, building structure, building damage index and photographs of buildings as a digital map. Using this database, we investigated the constructions of the age and sex of individuals and the spatial distribution of the dead, as well as the relationships, between the ages of houses and ages of the dead caused by the earthquake.

CONSTRUCTION OF THE BUILT ENVIRONMENT DATABASE

Nishinomiya City had a population of 411,882 and approximately 96,000 buildings at the time of the earthquake [The Administrative Bureau of the Ministry of Home Affairs, 1994]. It was reported that 1,108 deaths, 19,500 completely collapsed buildings and 16,300 partially collapsed buildings, were caused in Nishinomiya City by the Hanshin-Awaji earthquake disaster up to March 28, 1996 [The 21st Century Hyogo Project Association, 1997].

[1] *Earthquake Disaster Mitigation Research Center, (RIKEN), Japan. E-mail: hengjian@miki.riken.go.jp*
[2] *Earthquake Disaster Mitigation Research Center, The Institute of Physical and Chemical Research (RIKEN), Japan*
[3] *Earthquake Disaster Mitigation Research Center, The Institute of Physical and Chemical Research (RIKEN), Japan*
[4] *DPRI, Kyoto University, Japan E-mail: tanaka@imdr.dpri.kyoto-u.ac.jp*
[5] *Earthquake Disaster Mitigation Research Center, The Institute of Physical and Chemical Research (RIKEN), Japan*

Regarding the damage caused by the Hanshin-Awaji earthquake disaster and the situation in Nishinomiya City, five data sets exist: (1) urbanization area data, (2) real estate tax roll data before the earthquake, (3) data from the investigation of building damage, (4) human casualty data, and (5) photographs of the damaged buildings. We defined each building as a basic unit, and these five data sets were linked to each building respectively [Lu et al., 1999]. However, when the data were linked to each building, some problems arose, for example, the definitions for one building occasionally differed from others in the data, and the total number of buildings in these five data sets differed from each other. To solve this problem, it was necessary to determine a basic map. To this end, the urbanization area data in the digital map were used as a basic data set in the construction of the database. As a digital map, it has considerable detail and correctly depicts the distribution of buildings, roads, highways, railways, walls and other structures. A detached polygon of buildings in the digital map is defined as a building. The database construction and composition is shown in figure 1.

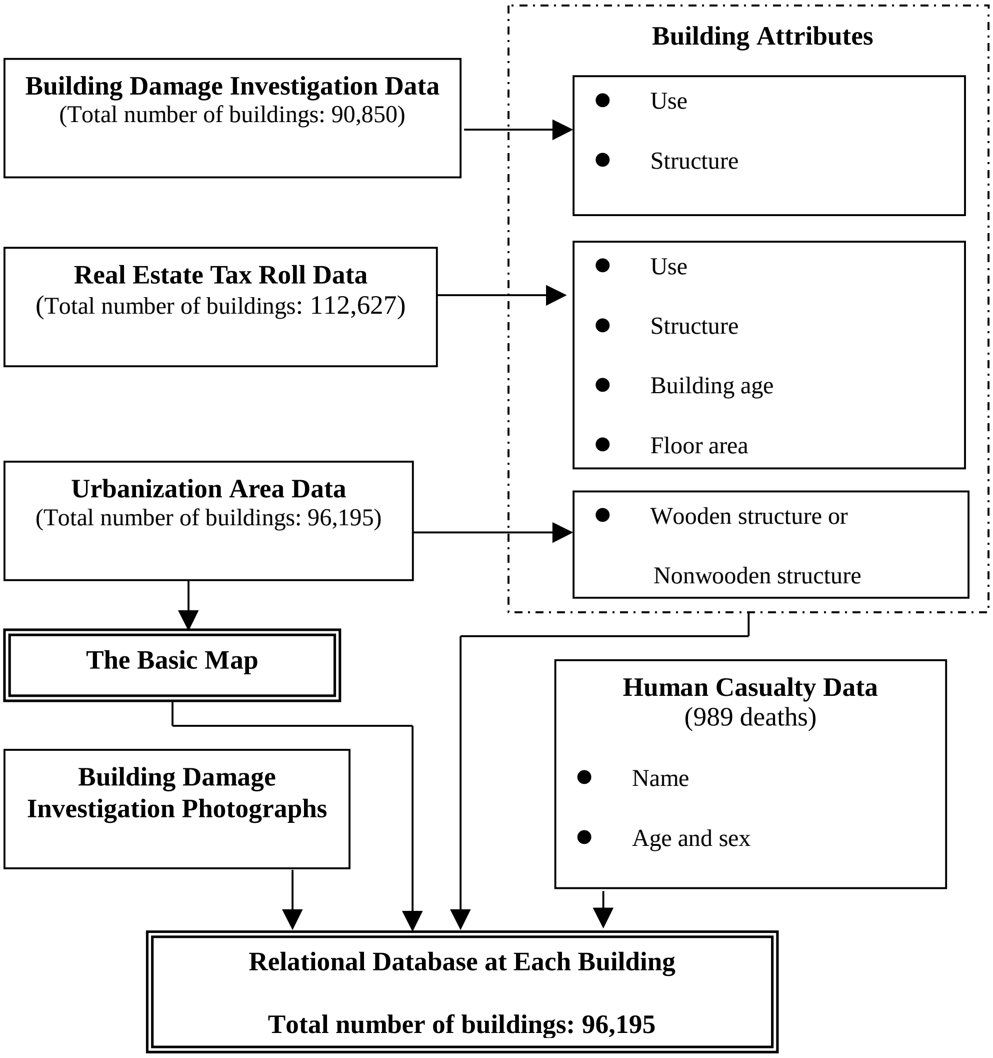


Figure 1: Composition of the database

EFFECTS OF ATTRIBUTES OF INDIVIDUALS TO CASUALTY DUE TO EARTHQUAKE

Method of Analysis

It is proposed that weak people in an earthquake, such as the aged, make up a large proportion of the victims. This suggests that these people are at a higher risk in an earthquake. It is clear that mortality risks differ according to the attributes of individuals. We investigated the relationships of the risk of mortality occurrence to age and sex of individuals and analyzed the effects of attributes of individuals to mortality caused by an earthquake through Weibull analysis. Weibull analysis is a useful method for analyzing the probability distributions of material damage or machine failure in reliability engineering [Makabe, 1998]. The failure distribution function (cumulative reducing rate function) in Weibull analysis is as follows.

$$F(t) = 1 - \exp\left[-(t-\gamma)^m/\eta\right] \quad (t \geq \gamma, m > 0, \eta > 0) \qquad (1)$$

m : shape parameter
η : scale parameter
γ : location parameter
In this paper, F(t) represents the cumulative mortality rate function, t represents the age of the dead, and the location parameter γ represents the initial value of age groups where the distribution patterns of the mortality rate are the same. The scale parameter η represents the unit of age groups. Therefore, it is the shape parameter *m* that expresses the distribution pattern of mortality occurrence. Based on the *m* value, the relationships of the risk of mortality occurrence to the age of the dead could be classified into three patterns:
$m < 1$: decreasing occurrence of mortality
$m = 1$: constant occurrence of mortality
$m > 1$: increasing occurrence of mortality
Using the above-mentioned GIS database, we calculated the *m* values in the different age and sex groups, and compared the difference between *m* values in normal times and in the earthquake.

The total number of the dead caused by the Hanshin-Awaji earthquake disaster in Nishinomiya City was 1,108 including the related deaths (deaths due to illness and so forth related to the earthquake) [The 21st Century Hyogo Project Association, 1997]. In this paper, the casualty data are based on the results of autopsies and do not include the number of the related dead. The number of the dead for which the age and sex of the individual were identified is 981, as shown in table 1.

Table 1: Number of the dead in the different age and sex groups

Age	Under 9	10~19	20~29	30~39	40~49	50~59	60~69	Over 70	Unknown	Total
Men	32	26	40	24	26	61	76	100	0	385
Women	26	31	60	27	53	82	108	205	4	596
Total	58	57	100	51	79	143	184	305	4	981

Comparison of Mortality Rates of Different Age Groups in Normal Times and in the Earthquake

To compare the difference between mortality rates in normal times and in the earthquake, we used the data of average mortality rates of different age groups in Japan in 1994 as the mortality rate in normal times [The Minister's Secretariat Information Department of the Ministry of Health and Welfare, 1995]. Because there were no great natural disasters or accidents which resulted in a large loss of life in 1994, the average mortality rate can be used as the mortality rate in normal times for comparison with that of the Hanshin-Awaji earthquake disaster.

Figure 2 presents the Weibull distributions of mortality rates for different age groups in normal times and in the earthquake. It is illustrated that in normal times there are three distribution patterns, under 15 years old, between 15 and 45 years old and over 45 years old. In the case of the earthquake, there are only two patterns and 50 years old is the turning point. Furthermore, the Weibull analysis of the mortality rate in different age groups divided by the turning points of 15 and 45 years old in normal times, and 50 years old in the earthquake have been carried out. The results are shown in tables 2 and 3. A turning point indicates that the distribution pattern changes at that age. To determine the turning point, several regression analyses regarding the different age groups have been performed, and the turning point was determined according to the result of the regression analysis which has the highest correlation coefficient at that age. However, to compare the difference of mortality rates in normal times and in the earthquake, the analysis of the mortality rate in the earthquake has also been carried out using the same age groups as in the analysis of normal times.

The relationships between the mortality rate and age of individuals in normal times can be expressed by three distribution patterns. The distribution of the mortality rate of the under-15-year-old age group exhibits a decreasing pattern, and the *m* value (0.16) is much less than 1. This indicates that in this young age group the mortality rate decreases with the growth of children. The *m* value in the 15-to-45-year-old age group is 1.22. The distribution of the mortality rate exhibits a roughly constant pattern. It can be considered that death in this age group is mainly by accidents. The *m* value in the over-45-year-old age group is 6.25; this is much higher than that for the between-15-to-45-year-old age groups. This indicates that, in normal times, the mortality rate of the over-45-year-old age group increases rapidly due to natural aging.

On the other hand, the distributions of mortality rates in the earthquake exhibit two patterns and 50 years old is the turning point. The *m* value in the under-50-year-old age group is 1.09, that is, it is close to 1. This indicates that the distribution of the mortality rate is a constant pattern. With age of over 50 years old, the *m* value becomes 4.13. This indicates that the distribution of the mortality rate changes to an increasing pattern.

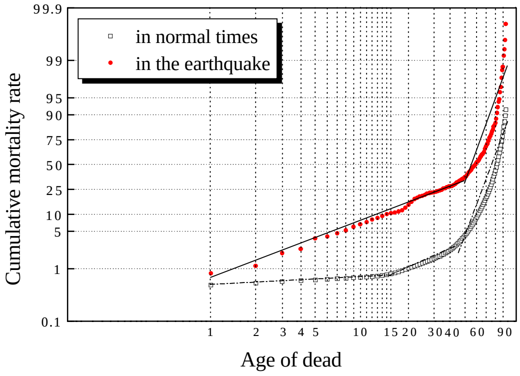


Figure 2: Weibull distributions of mortality rates in normal times and in the earthquake

Table 2: Results of Weibull analysis in normal times

Age groups	*m*	η	γ
Under 15	0.16	4.23×10^{14}	1
15~45	1.22	894.3	15
Over 45	6.25	85.4	45

Table 3: Results of Weibull analysis in the earthquake

Age groups	*m*	η	γ
Under 50	1.09	110.7	1
Over 50	4.13	64.5	50
Under 15	1.00	146.2	1
15~45	1.17	100.3	15
Over 45	3.80	63.6	45

A comparison of mortality rates in normal times and in the earthquake with regard to different age groups has been carried out. In the under-15-year-old age group the distribution of the mortality rate exhibits a decreasing pattern in normal times, and a constant pattern in the earthquake. Compared to other age groups, it shows the largest difference in the mortality rate between normal times and the earthquake. This indicates that the effects of the earthquake on people under 15 years old are the greatest among all age groups. It can be considered that children under 15 years old have a lower risk of mortality during their growth in normal times, however, they have a weaker capacity when a disaster occurs than other age groups do. The *m* values in the 15-to-45-year-old age groups are 1.22 and 1.17, respectively, in normal times and in the earthquake. Both distributions of mortality rates exhibit constant patterns. The distributions of the mortality rate in over-45-year-old age groups exhibit increasing patterns both in normal times and in the earthquake. However, with increasing age, the increase of the mortality rate in this age group in normal times (m=6.25) is higher than that in the earthquake (m=3.80). The distribution of the mortality rate of this age group in normal times reflects the natural aging process in humans. Mortality in an earthquake is due to accidents, and the distribution of the mortality rate is qualitatively different from that in normal times. The distribution of the mortality rate in this age group in the earthquake should also belong to a constant pattern. On the other hand, in the case of the aged, with increasing age, their physical functions such as strength and quickness of actions decreases, which results in a higher risk of damage in an earthquake, and the distribution of the mortality rate changes to an increasing pattern.

Relationship of Mortality Occurrence with Age and Sex of Individuals

Figure 3 shows the Weibull distributions of the mortality rate by different sexes (men and women) in the earthquake. This figure illustrates that for both men and women, the distributions of the mortality rate have the same two types of patterns, with 50 years old as a turning point. The results of the Weibull analyses are shown in table 4. The turning point is determined according to the results of regression analyses of different age groups.

Figure 3: Weibull distributions of mortality

Table 4: Results of Weibull analyses on groups by sex and age

Groups of sex and age		*m*	η	γ
Men	Under 50	0.96	106.8	5
	Over 50	4.69	62.2	50
Women	Under 50	1.24	105.9	5
	Over 50	4.91	64.7	50

For men, the *m* value (0.96) in the under-50-year-old age group is approximately 1 and the distribution of the mortality rate exhibits a constant pattern. It can be considered that people of different ages within this age group have approximately the same risk of mortality. However, as age increases to over 50 years old the *m* value rises to 4.69 and the distribution of the mortality rate changes to an increasing pattern. This indicates that the risk of mortality by the earthquake increases with increasing age. For women, the *m* value in the under-50-year-old age group is 1.26 and the distribution of the mortality rate exhibits an approximately constant pattern. However, as age increases to over 50 years old, the *m* value rises to 4.91. This indicates that the risk of mortality by the earthquake becomes significantly higher with increasing age.

Comparative investigations of mortality occurrence with regard to different sexes have been carried out. The distribution patterns of the mortality rate share common characteristics with a turning point at 50 years old for both men and women, and the risk of mortality increases when age is over 50 years old. The *m* values for women of all age groups are slightly higher than those for men, however, there is no significant difference between men and women. The distribution patterns of the mortality rate are nearly the same for both sexes.

RELATIONSHIP OF AGE OF DEAD TO REGIONAL DISTRIBUTION OF CASUALTY OCCURRENCE

The above-mentioned investigations indicated that the risks of mortality caused by the earthquake are different according to the age of individuals, with 50 years old as a turning point. It is considered that one of the main reasons for the rise in mortality risks in the over-50-year-old age group is that physical functions become weaker with increasing age. Besides collapse of buildings, myocardial infarction and shock could also result in casualty of the aged. The causes of casualty of the aged are more complicated than those of other age groups. It can be conjectured that casualties in young groups were concentrated in regions with a high degree of building damage, whereas the distributions of casualty of the aged were relatively widespread. To verify this conjecture on the basis of the above investigations, the total number of dead is classified into two types according to the sex of individuals, and each type is then classified into two groups by age, over 50 years old and under 50 years old. The regional distributions of mortality in each group have been investigated.

The distribution of buildings in Nishinomiya City is shown in figure 4. The northern area is mountainous, and there are few buildings in these areas. The southern seaside area also has relatively few buildings. The buildings and population are concentrated in the relatively narrow area between the Hanshin Railway and the Sanyo Shinkansen Line. Figures 5 and 6 show the distributions of mortality of different age and sex groups. The number of dead and locations of mortalities of the different groups are shown in table 5. From figures 5 and 6, it can be seen that mortalities are widely distributed in nearly all urban areas. There are no obvious relationships between mortality locations and age groups.

In addition, the causes of death and the distribution of damaged building in Nishinomiya City have been investigated. Damaged building is concentrated in the urban area, as shown in figure 7 [The Building Research Institute of the Ministry of Construction, 1996]. The total collapse rates are over 10% in nearly all urban area. In part of the center of urban area, the total collapse rates are over 50%. The afflicted area is divided into two groups according to the rates of total building collapse, over and under 50%.

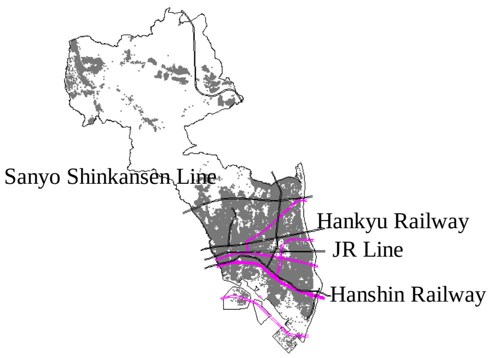


Figure 4: Distribution of buildings

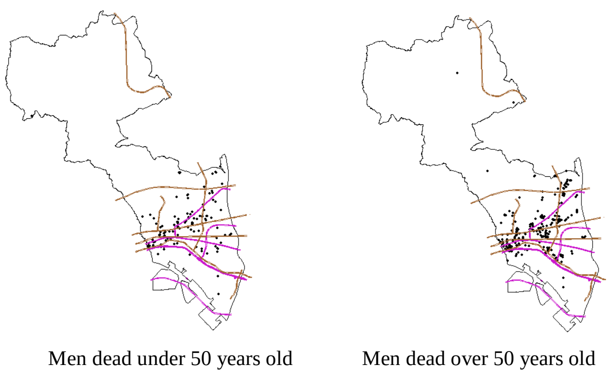


Figure 5: Distribution of men dead under and over 50 years old

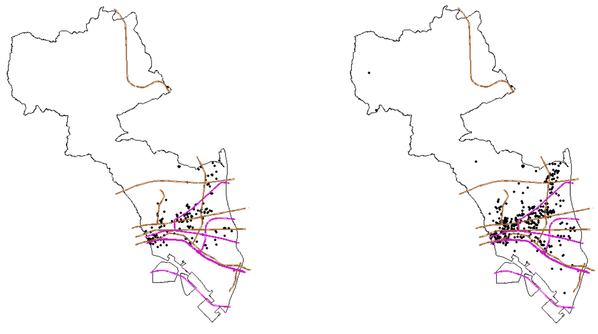


Figure 6: Distributions of women dead under and over 50 years old

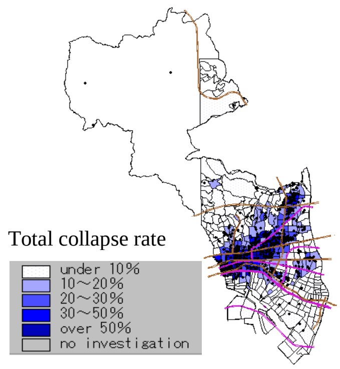


Figure 7: Distribution of damaged buildings

The Weibull distributions of the mortality rates of these two regional groups have been comparatively investigated. Table 6 lists the number of dead in these two regions in different age groups, and the results of the Weibull analyses are shown in table 7. Figure 8 illustrates the relationships between mortality rate and age group with regard to the total collapse rate. From the results of the Weibull analyses, it can be seen that there are slight differences in distributions of the mortality rate according to the total collapse rate. The distribution patterns of the mortality rate in the two regions are similar.

Table 5: Number of dead and injury locations

Sex	Under 50 years old		Over 50 years old	
	Deaths	Locations	Deaths	Locations
Men	146	123	235	233
Women	197	157	395	374

Table 7: Results of Weibull analyses on areas of differing damage rates by age

Total collapse rate	Age groups	m	η	γ
Over 50%	Under 50	0.92	140.50	5
	Over 50	4.62	64.42	50
Under 50%	Under 50	1.14	103.78	5
	Over 50	4.40	63.84	50

Table 6: Number of dead by age group and total collapse rate group

Age	Total collapse rate		Total
	Over 50%	Under 50%	
Under 10	13	45	58
10~20	11	46	57
20~30	12	87	99
30~40	11	38	49
40~50	14	65	79
50~60	20	124	144
60~70	36	145	181
Over 70	57	245	302
Unknown	0	4	4
Total	174	799	973

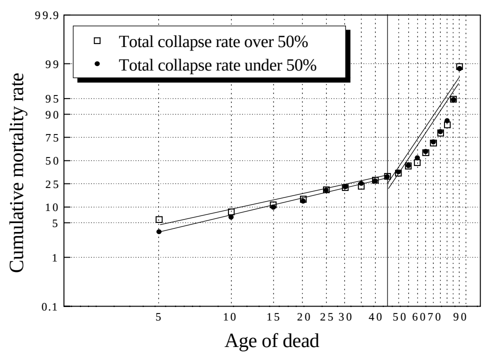


Figure 8: Weibull distributions of mortality rate for different groups of total collapse rate

The causes of death in Nishinomiya City have been concluded to be as follows.

A: crushed to death, pressed to death, organ damage due to pressure
B: suffocation by pressure, suffocation
C: contusion, bruising, bone fracture
D: death by burning, suffocation by smoke, death by pressure or burning
E: cardiac insufficiency, pneumonia, shock, death by exposure to cold

Table 8 shows the number of dead categorized by cause of death, age group, and sex of individuals. The number of dead due to cause E is fewest, and the number of dead due to cause D is also few because there was no large-scale spread of fire in Nishinomiya City during the earthquake. Over 96% of the total number of deaths are caused by direct physical blows such as cause A, B or C.

It can be considered that the reasons for there being no obvious relationships between the locations of mortality and age groups in Nishinomiya City are the centralization of the urban area and population in a relatively narrow area, the high rate of total collapse throughout the urban area, and the majority of deaths being caused by direct physical blows.

Table 8: Number of dead categorized by groups of causes

Causes of death	Men		Women			Total	Ratio*
	Under 50	Over 50	Under50	Over 50	Unknown		(%)
A: crushed to death, pressed to death, organ damage due to pressure	93	129	126	243	2	593	62.55
B: suffocation by pressure, suffocation	28	53	47	87	1	216	22.78
C: contusion, bruising, bone fracture	19	32	20	32	1	104	10.97
D: death by burning, suffocation by smoke, death by pressure or burning	6	4	4	9	0	23	2.43
E: cardiac insufficiency, pneumonia, shock, death by exposure to cold	1	5	0	6	0	12	1.27
Not mentioned	5	10	5	13	0	33	-
Total	152	233	202	390	4	981	100

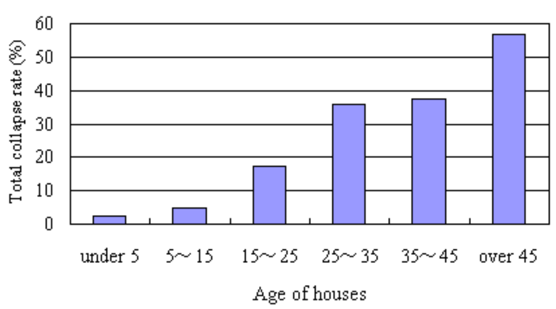
*: The ratio does not include the "Not mentioned" item

Based on the above investigations, it cannot be concluded that the age groups of casualties are not linked with the spatial distribution of mortality. Because the data of casualties used in this paper does not include the number of related deaths, which is over 100, collecting the data on related deaths and analyzing it should be the next step of this investigation.

RELATIONSHIP BETWEEN THE OCCURRENCE OF CASUALTY AND THE AGE OF HOUSES

It is clear that the mortality rate of the aged in the earthquake is significantly higher than that of the young. One of the main reasons is that physical functions and action sensitivity of the aged decline due to the aging process. Another reason that has been identified is that the aged lived in older houses in a greater ratio than the young. However, this remains to be confirmed. The data for Nishinomiya City were used in this paper to verify the relationship of the occurrence of mortality to the age of houses. It was confirmed by the built environment database that 973 of the total number of deaths occurred in 711 houses. The ages of 454 of the 711 houses have been determined from the real estate tax roll data. The number of deaths in these 454 houses was 625.

Generally, the age of houses is used as one of the criteria to evaluate the degree of house decrepitude. It was reported that the relationships between the ages of houses and degrees of house damage have been investigated in an area of Kobe City [Editorial Committee for the Report on the Hanshin-Awaji Earthquake Disaster, 1998]. It is clear that the older a house is, the higher the total collapse rate is. House damage is greatly affected by the age of the house. Figure 9 shows the relationship of the total collapse rate to the age of houses in Nishinomiya City. This figure illustrates the same result as obtained for Kobe City; the total collapse rate increases with increasing age of the house. Therefore, in this study, the age of the house is used as the criterion of the degree of house decrepitude.



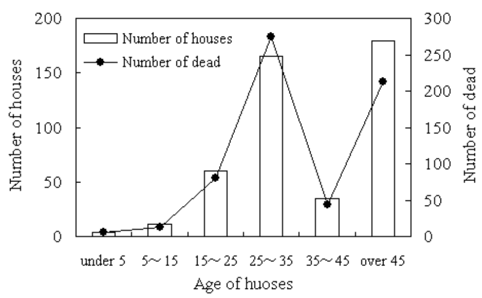


Figure 9: Total collapse rate in groups by age of houses **Figure 10: Age of houses and number of dead**

Because the building damage rate increases with the degree of house decrepitude, it can be considered that residents who live in decrepit houses have a higher risk of mortality. Figure 10 shows the relationship of the age of houses to the number of dead. Because the number of houses 35 to 45 years old is very few, the number of deaths occurring in this range of house age is also small. As a general trend, the older the houses were, the more mortality occurred. Figure 11 shows the relationships between the ages of the dead and the age of houses. It is clear that in houses over 50 years old, the number of deaths of individuals over 50 years old is much higher than that of individuals under 50 years old.

Table 9: Number of dead and average house age by age groups

Age of dead	Number of dead	Average age of houses	Variances
Under 50	221	35.26	202.31
Over 50	404	44.03	398.44

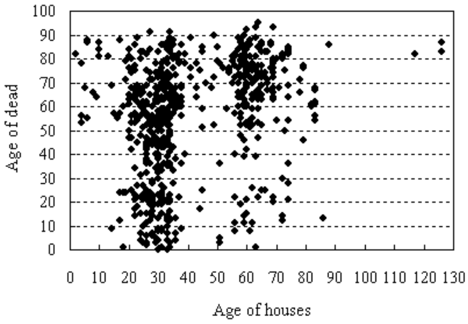


Figure 11: Age of dead and age of houses

A comparison of the results of statistical significant difference tests regarding the average age of houses inhabited by different age groups of people has also been carried out. Based on the results of the Weibull analysis in section 3, the dead are classified into the two groups of under 50 years old and over 50 years old. The average ages of houses and the values of variances regarding the two age groups have been calculated, as shown in table 9. It can be seen that the average age of houses inhabited by the aged over 50 years old is nine years older than that of houses inhabited by the under-50-year-old age groups. To test for a statistically significant difference, the values of a normal distribution, estimated from the sample variances, are used. A significant difference in the average house age between these two age groups was found at a 1% significance level. The result demonstrates, at least for Nishinomiya City, that the high ratio of the aged over 50 years old living in relatively old houses is one of the reasons resulting in the higher mortality rate of the aged than that of the under 50-year-old age group.

CONCLUSIONS

1. Through the Weibull analysis, the distributions of the mortality rate with regard to different age groups were clarified. The distributions of the mortality rate caused by earthquake have a turning point at the age of 50 years old. The distributions exhibit a constant pattern for under-50-year-old age groups and an increasing pattern for over-50-year-old age groups. By comparing the distributions between the mortality rates in normal times and in the earthquake, it was clarified that the effect of earthquake on people under 15 years old is higher than that on other age groups.
2. The regional distributions of mortality by earthquake have no obvious distinctions between different age groups.
3. Regarding the relationship of the age of houses to age of casualties, it is clear that the rates of mortality which occurred in older houses are rather high, and the high ratio of the aged living in relatively old houses is one of the reasons resulting in the higher mortality rate of the aged than that of the young.

REFERENCES

The Administrative Bureau of the Ministry of Home Affairs (1994), *The Population Handbook of Resident Fundamental Register*, p78 (in Japanese).

The 21st Century Hyogo Project Association (1997), *The Reconstruction of the Great Hanshin-Awaji Earthquake Disaster*, No.1, p59 (in Japanese).

Lu, H., Maki, N., Tanaka, S., Hashitera, S. and Hayashi, H. (1999), "Construction of a Built Environmental Inventory Database from the Great Hanshin-Awaji Earthquake", *Proceedings of the 6th Japan/United States Workshop on Urban Earthquake Hazard Reduction*, J-7-7.

Makabe, H. (1998), "An Introduction to Reliability Engineering", Japan Standard Association, pp97-142.

The Minister's Secretariat Information Department of the Ministry of Health and Welfare (1995), *1994 Summary Life Table*, pp14-17 (in Japanese).

The Building Research Institute of the Ministry of Construction (1996), *Final Report of Damage Survey of the 1995 Hyogoken-Nanbu Earthquake,* (in Japanese).

Editorial Committee for the Report on the Hanshin-Awaji Earthquake Disaster. (1998), *Report on the Hanshin-Awaji Earthquake Disaster*, 4, pp41-53 (in Japanese).