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ESTIMATION OF HUMAN CASUALTIES DUE TO URBAN EARTHQUAKES

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ABSTRACT

Human casualty data by the recent earthquakes in Japan and the United States were reviewed. In the last forty years before the 1994 Kobe Earthquake, the number of fatalities in Japan had been very few excluding events followed by major tsunamis or landslides. Deaths due to collapse of buildings had been almost negligible in number. But in the Kobe Earthquake, over five thousand people were killed mostly due to collapse of wooden houses. From death certificate data of the event, vulnerability of female and aged people was clearly observed. The fatality data from the 1989 Loma Prieta and the 1994 Northridge events were also examined. Although the collapse of transportation structures and buildings were the major causes of deaths, non-trauma deaths, e.g., heart failure, had a significant ratio. Based on these observations, methods of human casualty estimation were discussed. Methods to nominate major casualty patterns were recommended since the circumstances of casualties diverse in the recent urban earthquakes. It is also pointed out that, since the occurrence time of an earthquake affects the number and circumstances of human casualties, daily activities and locations of residents should be considered in casualty estimation.

KEYWORDS

Human casualty; fatalities; injuries; Kobe Earthquake; Northridge Earthquake, trauma; building collapse; human activities; scenario earthquakes.

INTRODUCTION

Estimation of human casualties is one of the most important issues in earthquake damage assessment for scenario earthquakes in Japan (e.g., Kanagawa Prefecture, 1993). Local governments and medical organizations prepare for future earthquakes based on the results of the estimation. An estimated number of deaths and injuries draws considerable attention of mass media and citizens. Recently, casualty assessments are also carried out immediately after earthquakes by real-time seismic damage estimation systems of local governments or fire departments. The results are used for emergency operation planning in an early stage. However, accuracy of such estimations are not high since casualty estimation functions are basically empirical. Damaging earthquake data are not enough in number and the past data are highly dependent on individual events due to difference in characteristics of affected area, time and era of the occurrence and extent of follow-on hazards, etc.

Earthquake disaster mitigation planning in Japan has been highly influenced by the lessons learned from the 1923 Great Kanto Earthquake, which killed about 140 thousands people mostly by associated fires. But buildings and social circumstances are quite different now, hence the feature of disasters may be quite different. Actually, before the Kobe (also called Hyogoken-Nanbu or Great Hanshin) Earthquake, no earthquake had killed more than one hundred people for the last 40 years except for two events which were followed by killer tsunamis. Landslides have been the second cause of deaths for many years. Only few people had been killed due to collapse of buildings in that period, hence non-structural causes of injury had drawn more attention (Okada, 1992). However, the primary cause of deaths in the world is still collapse of buildings (Coburn et al., 1992; Shiono et al., 1991), especially in developing countrie.

The circumstances of deaths were quite different in the Kobe Earthquake on January 17, 1995. Over five thousand people were killed mostly due to collapse of wood frame houses. It was the first time in the world that a densely populated modern city area was directly hit by very strong ground shaking. We should not miss valuable lessons learned from this event. An important lesson from the Kobe Earthquake is the influence of the earthquake occurrence time on casualties. If the Kobe event had occurred in a daytime, many more fatalities might be expected due to collapse of expressways, railways and office buildings. It is also pointed out that medical (non-trauma) and/or indirectly earthquake-related fatalities became a significant number, as also observed in the 1994 Northridge Earthquake.

In this paper, first, the profile of human casualties is addressed for recent earthquakes in Japan and California. Then, methods of human casualty estimation are summarized and discussed.

PROFILE OF CASUALTIES IN THE RECENT EARTHQUAKES IN JAPAN

Table 1 shows the summary of major earthquakes in Japan for the last thirty years. The data for older events were taken from the catalog compiled by Usami (1987) and those for recent events from statistics of prefectures. Damage data for residential buildings were shown in four categories: "totally collapsed" (including burnt for the Kobe event), "burnt", "heavily damaged", and "lightly damaged". Totally collapsed houses in the Hokkaido-Nansei-Oki event were mostly by tsunamis. It should be noted that "totally collapsed" means, in most cases, more than half of the value of a building was lost, not totally torn down. Number of burnt houses shows that major fires were followed in three earthquakes: the 1964 Niigata, 1993 Hokkaido-Nansei-Oki, and 1995 Kobe. Causes of damage to buildings are strong shaking, liquefaction and landslides in most cases.

Table 1. List of recent earthquakes in Japan with damage to residential buildings (source: Usami, 1987)

Earthquake	Year	Month /day	Hour :min.	Magnitude (JMA)	Totally collapsed	Burnt	Heavily damaged	Lightly damaged
Niigata	1964	6/16	13:01	7.5	1,960	290	6,640	67,825
Tokachi-Oki	1968	5/16	9:49	7.9	673	18	3,004	15,697
Izu-Hanto-Oki	1974	5/9	8:33	6.9	134	5	240	1,917
Izu-Oshima-Kinkai	1978	1/14	12:24	7.0	96	0	616	4,381
Miyagiken-Oki	1978	6/12	17:14	7.4	1,183	7	5,574	60,124
Nihonkai-Chubu	1983	5/26	11:59	7.7	986	5	2,115	3,258
Naganoken-Seibu	1984	9/14	8:48	6.8	23	1	86	473
Kushiro-Oki	1993	1/15	20:06	7.8	53	2	254	5,311
Hokkaido-Nansei-Oki	1993	7/12	22:17	7.8	487	107	400	4,854
Sanriku-Haruka-Oki	1994	12/28	21:19	7.5	72	0	429	9,021
Hyogoken-Nanbu (Kobe)	1995	1/17	5:46	7.2	100,302	~7,000	108,741	227,373

Table 2. Causes of deaths in the recent earthquakes in Japan (source: Matsuda and Ishimura, 1994)

Earthquake	Landslides	Tsunami & drown	Building collapse	Fence & fallen objects	Shock	Others	Deaths Total	Heavily injured
Niigata	4	5	7	5	7	5	33	117
Tokachi-Oki	33	3	1	8	3	5	53	121
Izu-Hanto-Oki	28	0	1	1	0	0	30	77
Izu-Oshima-Kinkai	24	0	0	0	0	1	25	34
Miyagiken-Oki	1	0	4	20	3	0	28	267
Nihonkai-Chubu	0	100	0	2	2	0	104	74
Naganoken-Seibu	29	0	0	0	0	0	29	3
Kushiro-Oki	0	0	0	1	0	1	2	116
Hokkaido-Nansei-Oki	29	193	0	0	5	4	231	66
Sanriku-Haruka-Oki	0	0	2	0	1	0	3	66
Hyogoken-Nanbu (Kobe)	34	0	5,000>	?	?	?	6,308	1,883

Table 2 shows causes of deaths in the 11 earthquakes according to Matsuda and Ishimura (1994). The major cause of deaths looks quite different in each event. Tsunami was mostly responsible for the fatalities in the 1983 Nihonkai-Chubu and the 1993 Hokkaido-Nansei-Oki events. Deaths due to landslides are seen in most events. Overturning of brick fences was the primary cause of death in the 1978 Miyagiken-Oki Earthquake. Deaths due to collapse of buildings were only few, fewer than those by fences and non-structural components, before the 1995 Kobe Earthquake. This fact can be suggested by the definition of "totally collapsed" mentioned above. It is also noted that no fire-related death was reported before the 1995 Kobe earthquake except for few fire-fighters.

The ratio of number of deaths and heavy injuries shows destructiveness of events. Tsunamis (Nihonkai-Chubu and Hokkaido-Nansei-Oki) and landslides (Naganoken-Seibu) are highly fatal; once involved, only a few survived. The breakdown of injuries is also available for some recent earthquakes. The causes of injuries also vary from event to event. In the 1993 Kushiro Earthquake, over 152 burns were reported since it occurred in a winter evening of a cold region. As buildings became stronger, building contents became major causes of human injuries in recent moderate earthquakes.

PROFILE OF FATALITIES IN THE 1994 KOBE EARTHQUAKES

The Kobe Earthquake hit a highly populated area of about two million population at 5:46 a.m. of January 17, 1995. Most people were sleeping at that time. The number and classification of casualties might be quite different if the earthquake occurred at different time of the day. The number of directly earthquake-related deaths was reported as 5,519 according to the Fire-Defense Agency of Japan as of December 27, 1995. At this time, 789 indirectly earthquake-related deaths were also recognized. Hence the official number of deaths became 6,308.

Table 3 shows a breakdown of cause of deaths due to the event compiled by the Ministry of Health and Welfare (1995) based on the population statistics. The survey was conducted by collecting death certificates with a description of earthquake-related death. Hence, the total number of deaths was different from that by the Fire-Defense Agency. Circumstances of deaths were still under investigation, but mostly due to collapse of wooden houses. Other circumstances includes fire-related (504), collapse of elevated expressways (14), a landslide in Nishinomiya City (34), gas poisoning in Awaji Island (4), etc. The fire-related deaths could not escape because they were mostly trapped by collapsed houses. It may be difficult to identify all the circumstances of death in this event because of too many victims in confused situations.

The estimated time of death and the place of death are shown in Fig. 1. Majority of the fatalities died within the day of the event (94.3 %), most of them soon after the main shock. The places of death were mostly at home (78.9 %) since the quake occurred early morning.

A detailed investigation of fatalities was also conducted by medical examiners of the Hyogo Prefecture (Nishimura et al., 1995). In the study, a total of 3,651 death certificates by medical examiners (2,416 cases in Kobe City) and other clinical doctors (1,235 cases) were collected in Hyogo Prefecture. The breakdown of deaths by sex is male (40.3 %), female (59.3 %) and unidentified (0.4 %). It is noticed that female deaths were 1.5 times more than male deaths.

Figure 2 shows the breakdown of deaths by age and sex. The number of deaths for each 5-year age-group increases rapidly for those equal or older than 50. The fatality rate of each age group in Kobe City was then

Table 3. Cause of deaths in the Kobe Earthquake (Ministry of Health and Welfare, 1995)

Cause of death	No. of deaths	Percent (%)
Asphyxia and body compression	4,224	77.0
Thermal burns and smoke inhalation	504	9.2
Head and cervical spine injury	282	5.1
Organ injury	55	1.8
Traumatic shock	68	1.2
Blunt trauma injury	45	0.8
Crush syndrome	15	0.3
Others	128	2.3
Unidentified	124	2.3
Total	5,488	100.0

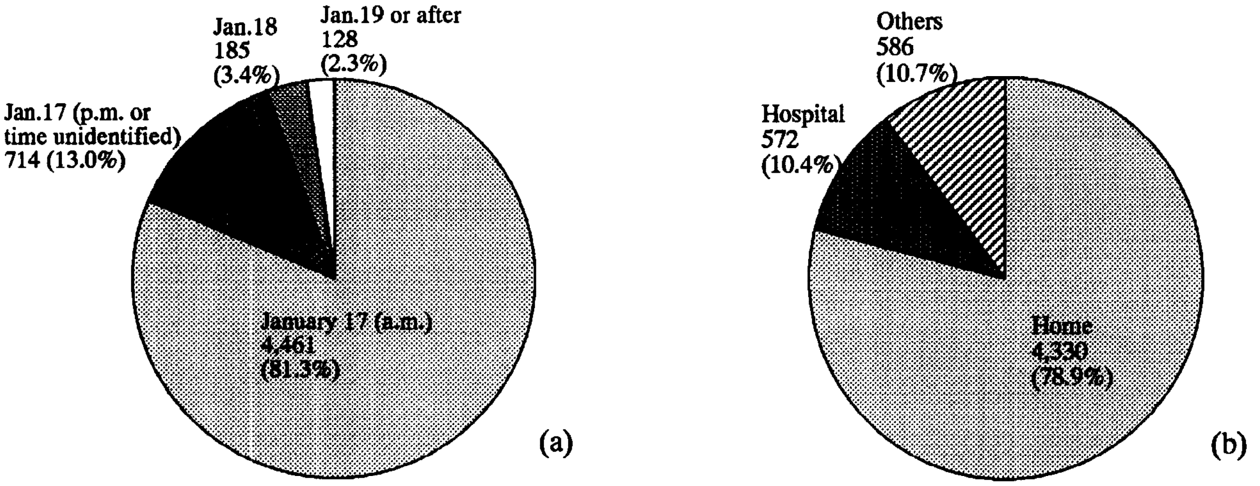

Fig. 1. Time of death (a) and place of death (b) due to the Kobe Earthquake

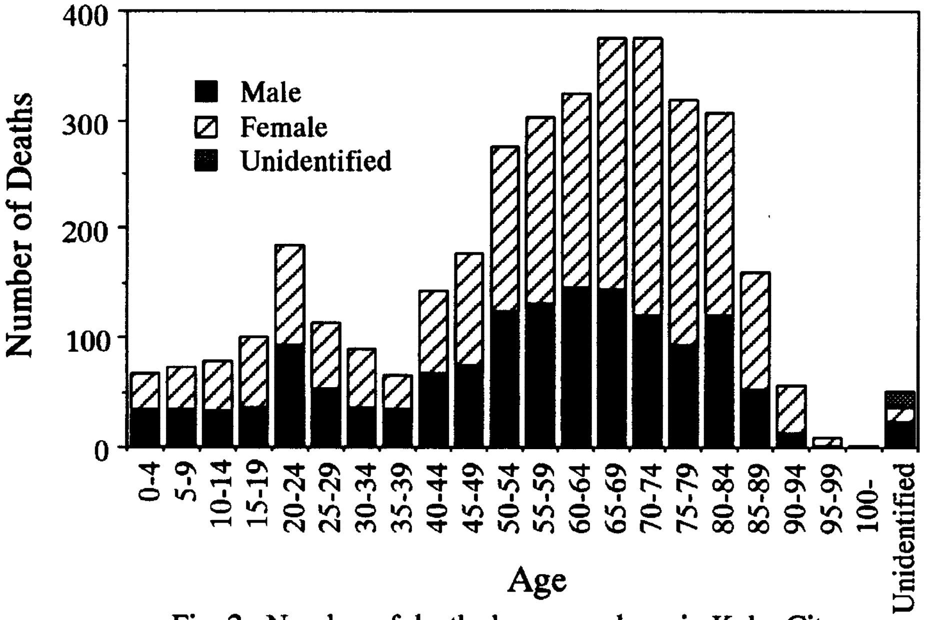

Fig. 2. Number of deaths by age and sex in Kobe City

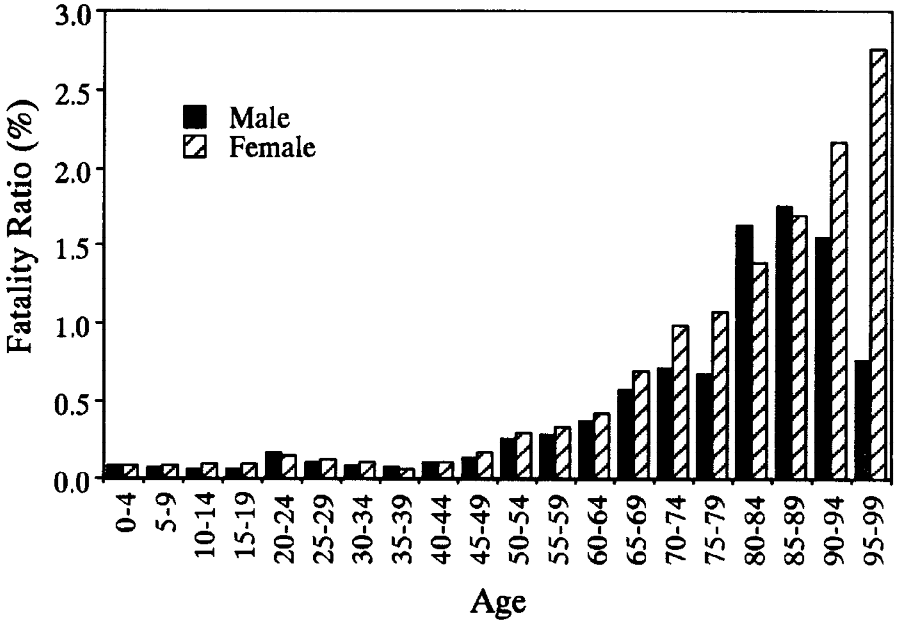

Fig. 3. Fatality ratio by age and sex in Kobe City

calculated as shown in Fig. 3 using the population data from the national census of 1990. It is clearly observed that the fatality rate increases rapidly as the age goes up, e.g., the rate exceeds 1.5 % for over 80, ten times more than that of under 50. A peak seen in age group 20-24 may be due to college students living alone in old wood frame apartment buildings. The higher fatality rate of female than that of male is observed for most of the age groups. Vulnerability of women and aged people in case of disasters, especially when trapped by collapsed houses, can be recognized as also seen in the 1948 Fukui Earthquake (Mochizuki et al., 1988) and in the 1945 Mikawa Earthquake (Matsuda and Ishimura, 1994). This observation could not be seen in the other recent earthquakes probably due to small numbers of fatalities.

The number of injuries by the Kobe Earthquake was 43,177 with 1,883 heavily injured, 26,615 lightly injured and 14,679 injury-extent under-survey due to the Fire-Defense Agency. The breakdown of injuries is still under survey. However, it might be difficult to get accurate statistics for injuries by the event since many injured people did not go to hospitals. Even the case they went, doctors could not take care for all the patients or did not have time to write medical reports.

PROFILE OF FATALITIES IN THE RECENT EARTHQUAKES IN CALIFORNIA

In the United States, fatality data were collected and classified for the two recent earthquakes in California, the Loma Prieta Earthquake of October 17, 1989 and the Northridge Earthquake of January 17, 1994.

Coroner and medical examiner records for all investigated deaths from seven California counties for 15 days following the Loma Prieta Earthquake were examined (Eberhart-Phillips et al., 1994). Data on the circumstances surrounding death were used to classify each case as "directly earthquake-related", "indirectly earthquake-related" or "not earthquake-related."

Fifty-seven (57) deaths in ten circumstances were judged as directly earthquake-related, including 46 on public roadways (40 on the I-880 elevated freeway, 5 on the 6th Street of San Francisco due to collapse of brick facade onto cars, and one on Bay Bridge), 5 at residence, 5 at business places or institutions, and one due to collapse of an earth embankment. It is noticed that collapse of transportation structures was most responsible for the fatalities (41) and that collapse of buildings/exteriors was the second (13). Three others were one by inhaling smoke from the Marina District fire, one due to collapse of a water-tank, and one due to the earth embankment mentioned above. It is also noticed that 29 out of 57 died outside county of residence. This fact suggests that the mobility of people should be considered in estimating human casualties due to urban earthquakes.

Six deaths were judged as indirectly earthquake-related. Two of them were due to heart attack and the others were individual reasons, e.g., carbon monoxide poisoning when using a portable generator, a motor vehicle collision with three horses wandering onto the highway. It seems difficult for some cases to judge whether "indirectly earthquake-related" or "not earthquake-related."

Coroner and medical examiner records were obtained and investigated for fatalities from the Northridge Earthquake (EQE International, 1995). The final number of earthquake-related deaths placed by the Los Angeles County Coroner was 60. The causes of death were grouped into two main categories, "trauma related" and "medical related." Trauma related deaths are due to injuries sustained while medical related deaths are those due to an illness or a medical condition, such as heart failure. Thirty-two (32) cases were judged as trauma and 28 cases as medical.

There were 15 circumstances that led to trauma deaths during the earthquake, 9 building-related and 6 street-related. Among 25 building-related deaths, 20 were due to structural failure (16 at Northridge Meadows apartment building), three due to shifting of building contents, one by fire on mobile home, and one due to other reason. Five deaths were considered as street-related, only one due to a freeway collapse and four by traffic accidents. Comparing with the Loma Prieta Earthquake, the number of deaths on street was much fewer, mainly because of the occurrence time (Loma Prieta: 5:04 p.m.; Northridge: 5:35 a.m.).

It is noted as many as 28 medical related deaths were followed by the tremor, most of them had arteriosclerotic heart disease. In some cases, it might be difficult to judge whether or not earthquake-related, especially for deaths many hours after the main shock. Actually, the FEMA's disaster relief program granted funeral expense to 117 requests of "earthquake-related death" after the event.

Table 4 compares fatalities of the two earthquakes using a unified classification. It is noticed that breakdown of the fatality categories is affected by the location and occurrence time of events. Although the number of fatalities looks rather few in recent earthquakes in California, it may not suggest few fatalities in larger magnitude or nearer earthquakes. The large number of fatalities in the Kobe Earthquake could not be estimated from the extension of recent events in Japan.

Table 4. Comparison of fatalities in the Loma Prieta and Northridge earthquakes

classification		Loma Prieta	Northridge
roadway-related	collapse of structures	41	1
	accidents	1	4
building-related	collapse of structures	6	20
	exteriors	7	0
	interior objects	0	4
	fire-related	1	1
other trauma	other structures	2	0
	indirectly related	2	2
medical		3	28
total		63	60

METHODS OF HUMAN CASUALTY ESTIMATION

There are several methods to estimate human casualties due to earthquakes. Basically, the methods can be classified into two categories: one estimates number of casualties from the number of collapsed houses (e.g., Ohta et al., 1983) and one considers various causes and estimates casualties for each cause. The former method was most commonly used in Japan for many years since the human casualties were mostly associated by building collapse till 1940's. Even the cases that casualties were not due to building collapse, it could be considered as a measure of shaking intensity. In the method, other parameters such as associated fire, time of the day, and period (era) of the event, were considered as modification factors.

The latter method was recently used in some human casualty estimations for scenario earthquakes in Japan (e.g., Kanagawa Prefecture, 1993) since it was hardly difficult to correlate human casualties and building collapses in the last 40 years before the Kobe Earthquake as described previously. Although the former method can explain most deaths in the Kobe Earthquake, it may be still difficult to explain human casualties, especially injuries, for moderate-damage earthquakes, which occur more frequently. Hence, the method which nominates each cause of casualties is discussed hereafter.

First, causes of death and injury must be identified. There are so many possible patterns of casualties, some of them have not reported yet. Low-probability events without enough data to construct estimation functions cannot be considered in a quantitative manner. Those events should be considered qualitatively in an earthquake consequence scenario. Coburn et al. (1992) classified earthquake-related deaths into three causes: structural damage, non-structural damage, and follow-on hazards. From the observation of recent earthquakes in Japan and the United States, medical (non-trauma) and indirectly-related deaths share a considerable ratio. Hence, those deaths should be considered at least in a scenario.

Follow-on hazards, typically represented by tsunamis, landslides and fires, vary case by case. Tsunamis and landslides affect specific areas. Land-use planning, education and early warning are most important for these hazards. Although they share a big portion of human casualties in Japan, they are not discussed here because estimation methods are quite different from those for the first two causes (structural and non-structural). Fires are also excluded since they are very unpredictable and highly affected by climate and other conditions.

In estimation of directly earthquake-related casualties, the population of an area to assess must be identified for the time of an earthquake occurrence. Since the daily mobility of people is very high in large city areas, it is essential to know the distribution of people in each time. Figure 4 shows the daily activity data of residents in Tokyo on weekdays (NHK, 1991). In the figure, activities of people is classified based on four locations: home, transit, workplace (including school), and others. Home activities are further divided into two: sleeping and other than sleeping. It is recognized that if an earthquake occurs in midnight, 98 % of people stay home, almost all of them sleeping. On the contrary, only 25.4 % stay home at about 11 a.m. The percentage of transit including commuting and other transit reaches its peak value 23.6 % at 8 a.m. Mass traffic accidents related to earthquakes may be the worst scenario in commuting hours. People staying in workplace or school become the peak ratio 61.5 % at about 11 a.m. Other activities become its peak during noon to 1 p.m., mostly having lunch at workplace or nearby restaurant. These typical daily activities must be considered when estimating human casualties in modern cities.

The region to assess human casualties should be divided into areas in which intensity of earthquake motion is considered to be almost equal. In most earthquake damage estimations in Japan, a square mesh of 500 m each side is used as the smallest division of the study area while in California, an area of postal zip code is often used (e.g., EQE International, 1995). In any case, first, population of people in each unit area must be estimated for typical locations; $n_i(t)$ is the number of people in each area locating place i (e.g., i=1: home, 2: workplace or school, 3: transit, 4: others). National census data and person trip data can be used to estimate this time-dependent population.

Population should be further broken down considering the vulnerability of circumstance. When people are at home or workplace/school, the structural type of building may be first considered, e.g., j=1: wood frame, 2: reinforce concrete, 3: steel, 4: masonry. A further classification by detailed construction type and year, which are highly related to structural vulnerability, is inevitable. In case of people in transit, classification may be, for example, j=1: on foot, 2: in train, 3: in automobile 4: in train/bus station. The "other places" are more difficult to list up and classify. Places where many people gather should not be missed, e.g., theaters, shopping centers, hospitals, and amusement parks.

Once the temporal population, $n_{ij}(t)$, locating place i with circumstance j is identified in each area, the probability of an injury level (e.g., death, heavily injured) of people is modeled by a vulnerability function as $P_{ij} = f_{ij}(A, age, sex)$, in which A is an index showing ground motion severity, e.g., the modified Mercalli intensity, the JMA (Japan Meteorological Agency) intensity, or the peak ground acceleration. If many data are available, like the case of trauma deaths in wood-frame houses in the Kobe Earthquake, the vulnerability function can be that of the shaking intensity and human parameters. But most cases, the vulnerability function can be modeled as a function of only strong motion: $P_{ij} = f_{ij}(A)$. The vulnerability function may also be constructed for types of injuries or deaths (e.g., structural, non-structural or burn).

It is possible to list up all the casualty cases using event trees (Murakami, 1992). However, if we consider many intermediate events (e.g., a building collapsed, trapped by the collapsed building, then not rescued) and their (conditional) occurrence probabilities, the final result of estimation (human casualties) is the products of such probabilities, which are very uncertain. Hence, the estimated casualties may contain large variability although it is theoretically more rigorous. However, in order to introduce the effect of retro-fit of structures and efficiency of rescue operations to a casualty estimation, such models are necessary to use. Especially, the number of casualties in transit is highly dependent on performance of transportation structures. Hence, whether structures fail or not under strong motion must be estimated first. Then, fatality or injury probability, which may be constructed from the experiences in Loma Prieta, Northridge and Kobe, must be multiplied to the number of people involved.

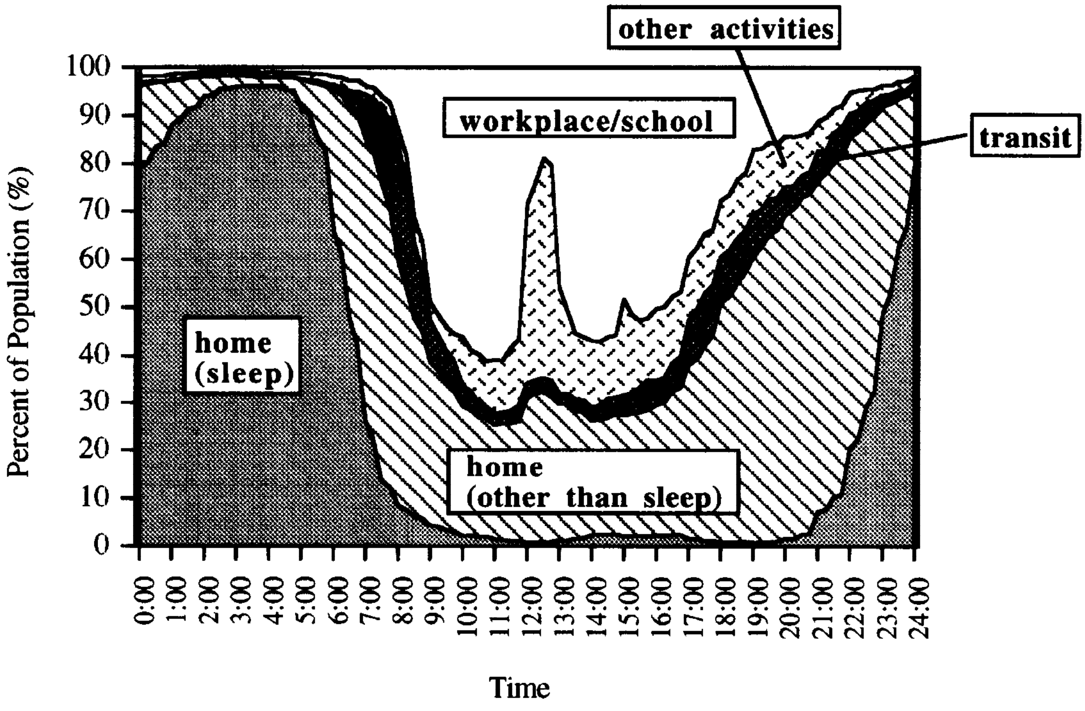

Fig. 4. Daily activity of residents in Tokyo on weekdays (source: NHK, 1991)

Finally, the total number of casualties in each area is obtained by taking a summations of all the cases. The estimation reflects the occurrence time of earthquake and the distribution of shaking intensity of the area.

CONCLUSION

Profile of human casualties in the recent earthquakes in Japan and the United States was examined. In the last forty years before the 1994 Kobe Earthquake, the number of fatalities had been very few except for the events followed by major tsunamis or landslides. The number of deaths due to collapse of buildings had been almost negligible. But in the Kobe Earthquake, over five thousand people were killed mostly due to the collapse of wooden houses. Reviewing the death certificates, vulnerability of female and aged people was clearly observed. The fatality data from the 1989 Loma Prieta and the 1994 Northridge events were also examined. Although the collapse of transportation structures and buildings were the two major causes of deaths, non-trauma deaths, e.g., heart attack, shared a significant ratio.

Based on these observations, methods of human casualty estimation were discussed. Methods to nominate major casualty patterns were highlighted since the circumstances of casualties diverse in the recent urban earthquakes. It is also pointed out that daily activities and locations of urban residents should be considered appropriately when estimating human casualties.

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