IMPORTANCE OF INDOOR AND ENVIRONMENTAL PERFORMANCE AGAINST AN EARTHQUAKE FOR MITIGATING CASUALTIES

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SUMMARY

This paper presents how human behavioral performance and environmental factors influence the casualty in case of tremors based upon recent earthquake experience surveyed in Japan. Respective examination of indoor (dwellings) and outdoor (streets) environments in view of risk of accidents during tremors provides check lists effective for mitigating casualties in one's daily surroundings.

INTRODUCTION

In recent Japanese earthquakes it seems that damage to non-structural building equipment and content are more responsible for human life losses and injuries rather than collapse of buildings. Reflecting this tendency well, the 1978 Miyagi-ken-oki earthquake which attacked a large city of Sendai has triggered a serious and wide concern over the cause of human casualties. In case of the earthquakes prior to 1978, though, our knowledge is quite limited and has not been enough to analyse cause and influential factors of casualty occurrences due to earthquakes. Situations in other countries are almost similar to those in Japan and only a few studies are known in the 1976 Guatemala and the 1979 Tumaco, Colombia earthquakes (Ref.1 and 2).

The authors have been continuing field surveys on human behaviors during and after an earthquake by means of retrospective questionnaire and interview methods (Ref.3 and 4). Through this study, occurrence of human casualty has been found to be dependent upon human behavioral characteristics and environmental performance. This paper introduces these survey results and describes human damages collected from various earthquake reports and papers from a view point of cause, frequency and process of accidents.

AN OUTLINE OF RECENT EARTHQUAKE CASUALTY IN JAPAN

Major Cause of Death and Injury In order to understand a general feature of recent casualty occurrence, Japanese destructive earthquakes since 1960 are listed with parameters and damages in Table 1-a. Casualty threshold in eathquake magnitude (M_{JMA}) seems to be around 6.5 and 7.0 for inland and coastal shocks respectively. Among four major causes of earthquake casualty, tsunami inundation and landslide will not be studied here because they are more dependent upon location of towns and villages rather than human behaviors and surroundings. Vibrational effects and emotional shock, of our concern, caused many deaths at the 1964 Niigata, the 1968 Tokachi-oki and the 1978 Miyagi-ken-oki earthquakes.

Personal records and detailed information of the wounded are less found than those of the dead, so that its distribution by causes in Table 1-b is

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Table 1-a Destructive earthquakes in Japan (1961-1983) and their damage

Earthquake Location	Date	Local Time	M (JMA)	Damaged Heavy	Damaged Part	Dead	Injured	Cause of Death Tsunami	Landslide	Shock	Vibration
Kitamino	19 Mar.1961	14h33m	7.0*	12	3	8	43	0			
Miyagi-ken-hokubu	30 Apr.1962	11h26m	6.5*	369	1542	3	276	0	0	2	1
Niigata	16 Jun.1964	13h01m	7.5	1960	6640	32	447	5	3	6	18
Ebino	21 Feb.1968	10h45m	6.1*	368	636	3	44	0	2	1	0
Tokachi-oki	16 May 1968	09h49m	7.9	673	3004	53	610	3	33	3	14
Nemuro-hanto-oki	17 Jun.1973	12h55m	7.4	2	1	0	28	-	-	-	-
Izu-hanto-oki	9 May 1974	08h33m	6.9	134	240	30	102	0	28	0	2
Oita-ken-chubu	21 Apr.1975	02h35m	6.4*	77	115	0	22	-	-	-	-
Izu Oshima-kinkai	14 Jan.1978	12h24m	7.0	96	616	25	205	0	25	0	0
Miyagi-ken-oki	12 Jun.1978	17h15m	7.4	1383	6238	28	4000	0	1	3	24
Urakawa-oki	21 Mar.1982	11h32m	7.1	13	28	0	167	-	-	-	-
Nihonkai-chubu	26 May 1983	12h00m	7.7	1584	3515	104	324	100	0	2	2

* : inland earthquakes

Table 1-b Causes of casualty due to recent Japanese earthquakes

Earthquake	Tsunami	Landslide	Shock	Fall Down	Falling Object	Glass Cut	Burn Scald	Else	Sum	Notes
1964 Niigata	0	7	1	63	28	-	3	5	107	Niigata city
ditto	0	0	2	25	38	-	1	0	66	Yamagata, Akita pref.
1968 Tokachi-oki	0	8	4	39	62	-	8	0	121	Aomori pref. SRS
ditto	0	19	2	18	12	-	3	1	55	Aomori,Hachinohe city
1974 Izu-hanto	0	6	0	20	37	-	0	14	77	Shizuoka pref.
1978 Izu Oshima-	0	0	0	7	8	-	4	10	29	Shizuoka pref. SRS
kinkai	0	0	0	7	21	-	13	1	42	Shimoda city
1978 Miyagi-ken-	0	0		682	675	698	93	993*	3142	Sendai city.Medical
oki	0	0	-	290	487	290	50	173*	1291	Miyagi pref. Police
1982 Urakawa-oki	0	0	3	15	77	13	41	0	149	Police
1983 Nihonkai-chubu	115	2	32	58	18	8	2	0	235	Akita,Aomori pref.

*: may include shock. SRS: Seriously injured.

still tentative. Tsunami and landslides are not as dominant among the wounded as among the dead probably because of their higher rate of death resulting from accidents. Vibrational effects are further classified here. "Fall down" is defined as an accident resulting from human movement such as a fall from higher places, a roll down at the stairs and a fall down on a flat floor. On the other hand "falling objects" means an accident attributed to movement of objects rather than of people and includes drop of something heavy, overturned furniture, destruction of block fences and so on. Accidents due to "fall down" seem to happen as far as seismic intensity allows one to walk around, while injuries due to "falling objects" are likely to increase in number at larger intensities.

Relation with Seismic Intensity There is no doubt that strength of earthquake ground motions is the basic cause of human casualty. Fig.1 examines the relationship between casualty occurrence rate (=sum of the dead and the wounded / population) and seismic intensity. This figure illustrates that injuries start to appear at around 5.0 in JMA intensity , rise with intensity and reach maximum value of about 0.8%, which is valid, though, up to intensity 6.0 and under the condition of no extensive fire nor a large scale tsunami inundation. Injury rate can be much higher within a limited small area. As for scatters among earthquakes, it can be pointed out that casualty rate is smaller at the 1983 Nihonkai-chubu earthquake than at the others. This may be explained by the fact that at the 1983 event there appeared

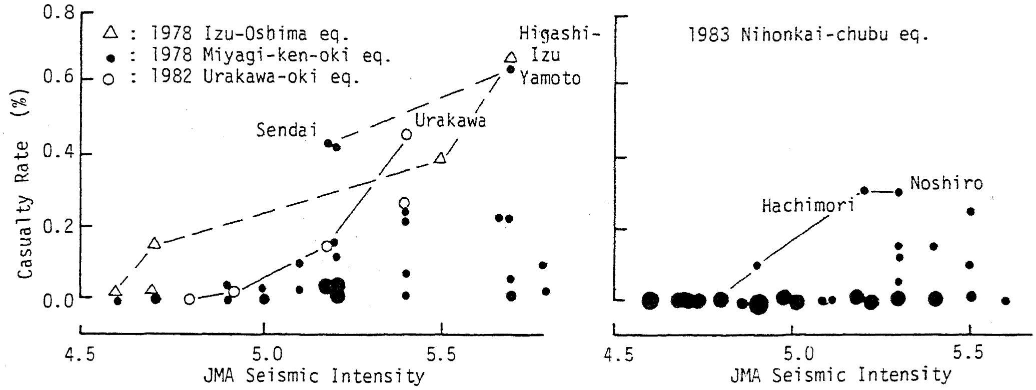


Fig.1 Casualty rate in relation with JMA seismic intensity.

relatively small acceleration (around 150gal) and limited overturn of furniture in contrast with extensive ground cracks and heavily damaged dwellings due to liquefaction. Scatters among towns and villages at the same earthquake suggest existence of other influential factors than seismic intensity (though some may be attributed to vague definition of injury).

HUMAN BEHAVIORAL PERFORMANCE

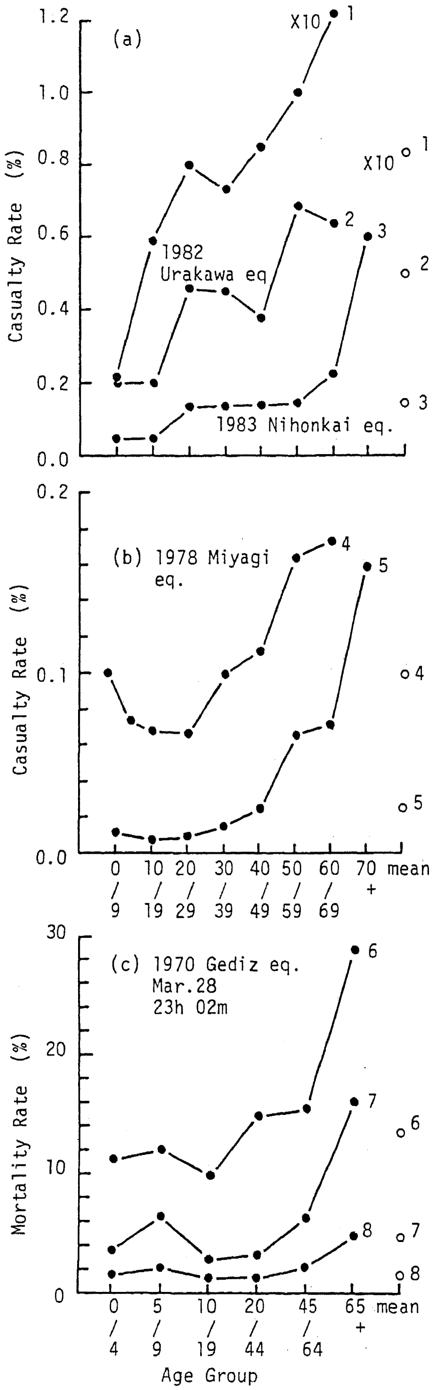
Human behaviors and personal characteristics often accelerate or suppress casualties due to earthquakes. For example a burn or a scald related with an action to put out fire device indicates higher percentage at the 1978 Izu Oshima-kinkai earthquake (34% using stove, 16% using gas cooking heater) and at the 1982 Urakawa-oki earthquake (95% using stove, 13% using gas) (see Table 1-b). A behavior to support shaking furniture which prevents injuries under moderate shaking turn out dangerous in higher intensities. Some people even rush out from windows of upper floors to suffer a fracture of bones.

As a more generalized rule, age dependence is depicted in Fig.2. Both serious and slight injuries show definite increase in percentage with ages at the several recent earthquakes in Japan. The similar trend is found in case of the 1970 Gediz, Turkey earthquake which occurred at 23h 02m on March 28th (Fig.2-c). Though most people were sleeping at home at that time, the tremor seems to have been more destructive for elder population.

The reason for this is older people's difficulty in quick movement under shaking environment and their weakened bodies which can be seriously wounded in a small accident. In fact age affects mortality rate due to daily life accidents in a manner similar to an earthquake (Fig.2-d). Children under 9 year of age get off unhurt more in earthquakes than in daily circumstances, probably because of successful protection by young parents and other adults.

INDOOR ENVIRONMENTAL FACTORS

<u>Dwelling Area and Casualty</u> Casualty dependence on area of houses is found in the result of questionnaire survey performed at the 1982 Urakawa-oki earthquake occurring on 21 March, Sunday at 11h32m (Ref.4). Among 899 households consisting of 2957 members surveyed in Urakawa town, 225 (8.4%) were injured and 24 persons (0.9%) received some medical treatment, which is



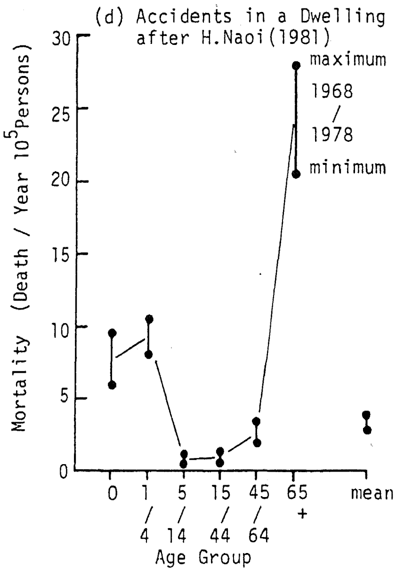


Fig. 2 Casualty and mortality rates as a function of age groups.

1. Questionnaire survey in Urakawa town
2. Patients in Urakawa town
3. Excluding tsunami in Noshiro city
4. Listed by police in Sendai and other 3 cities
5. Seriously injured and killed in Sendai city
6. Akçaalan town (236 death/1707 population)
7. Gediz town (360 death/7486 population)
8. District average

consistent with patient appearance rate of 0.5%. Using this data, Fig.3 illustrates the relation of injury rate versus number of dwelling rooms per household. Area of a room is mostly from 7 to 13m^2. Injury rate increases with decreasing number of rooms and is especially high in 2-3 room dwellings. As for the types of dwellings, injury rate of 8.3% for a detached house was found to be smaller than 14.3% for an apartment and 14.2% for a multi-purpose dwelling.

After the 1978 Miyagi-ken-oki earthquake, interview surveys were conducted choosing two different dwelling types in the vicinity on how inhabitants behaved against the shock. One is the apartment houses of 5-story reinforced concrete construction without any structural damage located in Sendai city (Ref.3). The other is detached houses classified into heavy damage by the Izumi city municipality. When comparing the two results as shown in Fig.4, the injured at the apartments amount to 29 out of 243 who were at home and far exceed that of the detached type, one out of 43 occupants. A probable reason of this difference is that the area of most of the detached dwellings is more than two times larger than that of the other. Incidentally in the surveyed apartments, 26 (22.0%) were injured among 118 housewives, while only 3 (2.8%) were injured among 107 children. This fact tells how housewives behaved actively and protected their children well. Causes of wound are cut by glass (10), falling objects (6), bump or graze (8) and falling down from the stairs (2).

Influential Factors on Casualty at Home

The preceding discussions have indicated how extremely small living space amplify risk of casualty at home. Ordinary houses in Japan are not only small in space, but also are occupied by plenty of contents and furniture which may attack the inbabitants during tremors. Average number of rooms is much smaller in densely inhab-

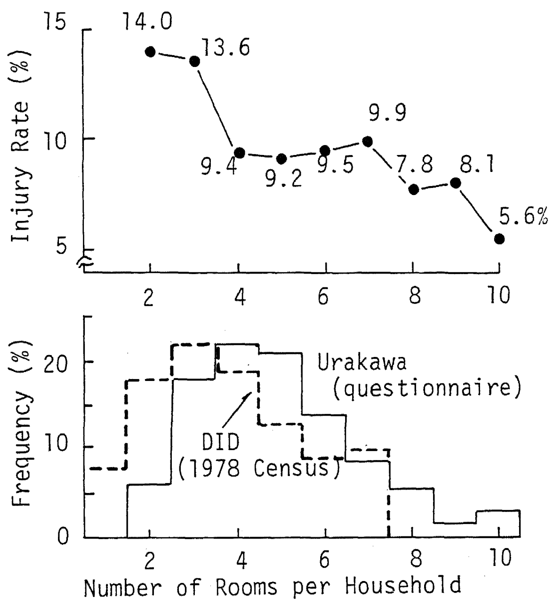


Fig. 3 Injury rate as a function of number of dwelling rooms per household surveyed in Urakawa town at the 1982 Urakawa-oki earthquake. The lower figure is frequency distributions of number of rooms in Urakawa town and in DID (Densely Inhabited Districts) all over Japan.

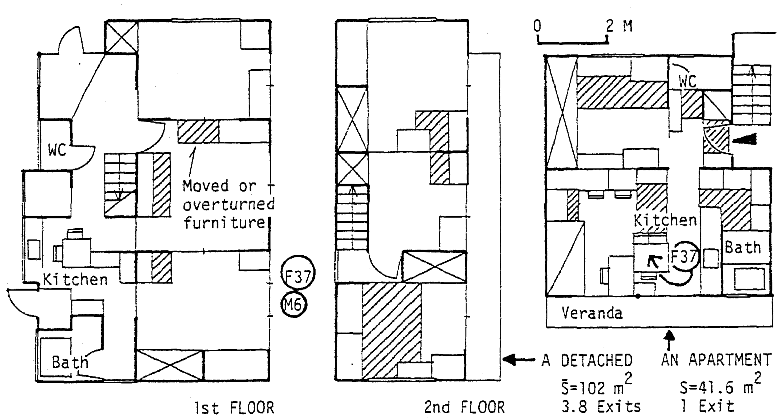


Fig. 4 Compared plans of a typical detached house (left) and an apartment (right) disturbed by the 1978 Miyagi-ken-oki earthquake.

Table 2 Factors dominating earthquake casualty at home

Factors	Items		Control
Direct factors	I. Seismic intensity		×
	II. Falling objects (equipment, furniture, contents)	Aseismic stability	△
		Disposition	△
		Weight	○
		Height	○
		Fracture	○
Accelerating factors	III. Dwelling space	Area	△
		Type	△
		Plan	△
	IV. Behavioral performance	Family constituent	×
		Child, disabled	×
		Role	×

ited districts (DID) than in rural areas as Fig.3 shows, which threats an outbreak of human damage in metropolitan areas. If the Miyagi-ken-oki and the Urakawa-oki earthquakes should have occurred during nighttime instead of daytime, more people living in smaller houses must have been wounded to further serious degree.

In addition to space, a single family dwelling and an apartment house have different characteristics each other from a view point of safety against earthquakes. The former is attached to the ground and provides many openings suitable for evacuation. The latter especially of high rise is separated from the ground, has a few limited emergency exits, dangerous elevators and stairs. Each environment naturally invites different human responses against seismic shaking and results in different patterns and degree of casualties. Based on these considerations, factors which may influence the indoor human casualty are classilied in Table 2 so as to help disaster prevention at family level.

OUTDOOR ENVIRONMENTAL FACTORS

Among outdoor environments, streets are critical in view of peoples' safety at earthquake occasions. They can be characterized by linear continuous space open upwards along which passersby go and come. Either one from neighborhood or a complete stranger is less familiar with the details of the street than of one's own home and therefore is exposed to various risk of injury and death such as heavier objects falling from higher places in streets than indoors. Examples are, i) Falling objects such as window panes, outer walls, signboards and roof tiles, ii) Falling down of fences, gateposts and vending machines, iii) Trapped in cracks and drops on the ground, and iv) Car accidents.

In such environment typical human responses against an earthquake can be a) no movement possible and sitting down, b) movement toward the center of street, and c) running through the street full of danger.

Field Inspection of Fatal Accident Sites Nineteen people were killed and many more were wounded under destructed concrete block fences, stone fences or gatepoles when the 1978 Miyagi-ken-oki earthquake occurred late in the afternoon (17h 15m) (Table 1). Most of the victims were either children or the old. Poor workmanship of fences and neglected poles should be blamed as the direct cause of the accidents, however, there remains a question if

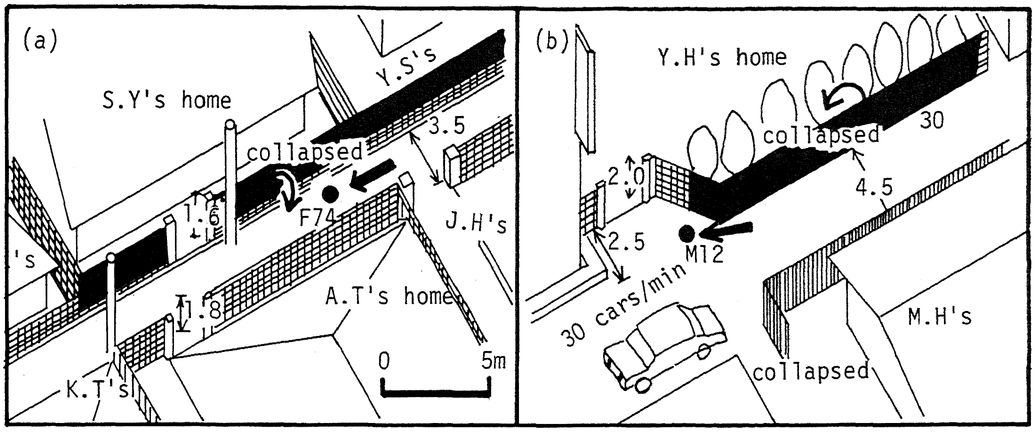


Fig. 5 Examples of sites in Sendai city where fatal accidents occurred at the 1978 Miyagi-ken-oki earthquake.

Table 3 Factors dominating fatal accidents in a street

Factors	Items		Control
Direct factors	I. Seismic intensity		×
	II. Falling objects (fence, glass)	Aseismic resistance	△
		Height	○
		Weight	○
		Fracture	△
		Length	○
Accelerating factors	III. Space	Street width	△
		Traffic volume	△
		Open space	○
	IV. Behavioral performance	Age, sex	×
		Baggage	×

environmental factors have nothing to do with it. In order to clarify this point, 7 sites where fatal accidents happened were visited and inspected in Sendai city.

Fig.5 illustrates a few examples of such accidents. A 74 year old woman who was walking for home after shopping was burried under a fallen concrete block fence of 1.6m height (Fig.5-a). The street is 3.5m wide, quiet in a residential district, though surrounded by continuing fences.

The next site in Fig.5-b is a 4.5m wide street crowded with heavy traffic (about 30 cars/minute). There is no sidewalk here. According to an eyewitness, a junior high student (12 year old boy) on his way back home was first hit by a car and bumped against the gatepole. A stone fence fell down not into the street but into the owner's plot. This case was brought to trial on responsibility.

A 6 year old girl playing on a bicycle was killed by a concrete block fence in an alley with little traffic. Considering the road width (3.5m) and the height of the fence (1.8m on both sides), no safe room seems to be left for survival. Another problem to be mentioned here is that there is no suitable playing lot in her sprawling neighborhood.

Factors Dominating Street Accidents From the case studies above, factors which may affect street accidents at an earthquake are classified as in Table 3. A space of 100cm wide, 80cm deep and 180cm high is the minimum necessity for an adult (Japanese) to walk safely. Thus assuming a 150cm high fence to fall down, an alley with little traffic must have at least 4.5 m width. In case of a street crowded with heavy traffic, even a width of 7.5m is not sufficient to remove risk of fatal accidents. If it is difficult to extend the width of streets, height of fences should be limited in accordance with other conditions.

Average length of concrete fences measured after the quake was about 10m in Sendai city. How long will it take to run through a segment of street surrounded by such continuous fences? The walking performance under seismic shaking seems to be deteriorated as 0.5m/sec or less and to differ according to one's attributes and circumstances. Therefore it must be very difficult to escape from dangerous fences in a short time from the perception of a quake to its major shaking.

CONCLUDING REMARKS

Human casualties due to earthquakes are affected by the major factors, that is, strength of seismic shaking, human behavioral performance and environmental performance. This paper has demonstrated how typical parameters such as seismic intensity, age, area of dwellings and street surroundings have actually influenced the casualty experience at the recent destructive earthquakes.

In order to mitigate life losses and injuries caused by earthquakes, it is more important and effective to consider various environmental factors and to attack the problem from various angles rather than to emphasize only structural strengthening. We cannot expect local governments or any public authority to know and remove everything dangerous in our daily environments. Instead this study helps citizens to explore a way of attaining family level safety against earthquakes in a systematic manner from the inside of one's house, outdoors in the neighborhood to the area within a walking distance.

The followings are the problems left for future study. First, although the frequency of casualty occurrence was dealt with, the severity or the quality of injuries, which is also significant, were not well analysed. Second, it is necessary to clarify inter-related factors and to develop some experimental equations in a quantative manner for discrimination and estimation of human casualties.

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