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Investigation of Human Injuries during the July 26, 2003 Northern Miyagi Earthquake with Focus on Furniture Overturning

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ABSTRACT

In the morning of 26 July 2003, a powerful shallow inland earthquake of Magnitude 6.4 on the JMA scale occurred in northern Miyagi Prefecture, Japan. Severe damage was concentrated in several towns around the epicenter because of the medium-sized earthquake, shallow focus and high frequency predominance. The Architectural Institute of Japan (AIJ), dispatched members of the technical working group to investigate the earthquake damage and learn lessons from the disaster.

We analyzed the results of the investigation regarding (1) human injuries, the causes and distribution; (2) estimation of furniture overturning; (3) relationship between structural damage and overturning damage of furniture in buildings; (4) relationship between the furniture overturning ratio and the following preparedness ratio based on a follow-up survey in the focal area.

The potential for human injury in earthquakes is increasing due to urbanization, high rise buildings and the aging of society.

1. INTRODUCTION

A powerful shallow inland earthquake of magnitude Mj=6.4(JMA scale) occurred at 7:13 JST on 26 July, 2003 in northern Miyagi Prefecture, Japan (2003 Northern Miyagi Earthquake). The epicenter was located at a depth of 12 km at 38.40˚ N, 141.17˚ E. On the same day, a foreshock and the largest aftershock of Mj=5.6 and Mj=5.5 hit the same area at 00:13 JST and 16:56 JST with epicenters approximately 3 km and 11 km north of the mainshock respectively. The strongest ground motions in seismogram history were recorded and very high seismic intensity reaching upper 6 on the JMA scale, which corresponds to about 10 on the MMI scale, were observed at many earthquake sites.

These earthquakes caused a total of 675 injuries; of which 51 persons were seriously injured. Of the 16,060 houses that were damaged, 1,276 houses collapsed. Fortunately, no fatalities or missing persons were reported. According to the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications, the economic loss was over 32 billion yen. As the earthquake was medium-sized, with shallow focus and high frequency predominance serious damage was concentrated in several towns around the epicenter. The disaster relief law was applied to five towns: Naruse, Yamoto, Kanan, Nango and Kashimadai Town.

Over the last one hundred years, the area has suffered damage from both inland and oceanic earthquakes. Kagami (2005) reported on the seismological and geological environment in the area affected by the 2003 Northern Miyagi Earthquake. Inland earthquakes such as the 2003 Northern Miyagi Earthquake occurred in 1962 with Mj=6.5 and in 1900 with Mj=7.0. Plate boundary earthquakes also periodically occurred at an average interval of 37 years. Earthquakes of 7.5 magnitude occurred off Miyagi Prefecture in 1978, 1936, 1897 etc. The most well-known seismic disaster is the Off Miyagi Earthquake that occurred in 1978. Reoccurrence is expected in the near future with extremely high probability.

The total population of the five towns is approximately 80,000, of which 675 were injured. Most of the injuries occurred in Yamoto Town, which accounts for approximately 70% of the total injuries. The ratio of injured people to the population in Yamoto Town is approximately 1.3%. The high level of injury was mainly due to the high population concentration and strong seismic ground motion in this town. Human injury was investigated by NHK: Japan Broadcasting Corporation, IFD: Ishinomaki Fire Department and the AIJ Investigation Committee. As there was little information on injuries reported to the Disaster Countermeasures Headquarters in Miyagi Prefectural Government, an immediate hearing survey was conducted in hospitals in the focal area to identify the causes of the injuries. The investigation showed that more than half of all injuries were caused by overturning furniture and falling objects.

In this study, the earthquake is outlined and human injury due to overturning furniture is described. Finally, the lessons of the earthquake disaster are highlighted.

KEY WORDS: 2003 Northern Miyagi Earthquake, human injury, furniture overturning, fragility curve, earthquake preparedness

Table 1. Municipal area and population of the five towns

Towns	Population*1 <A>	Area (km^2) <B>	Density per km^2 <A/B>	Farmhouses ratio*2	Population*3 <C>	Population ratio <A/C>
Yamoto	32,025	49.81	642.9	13.7	22,187	1.44
Kanan	18,081	69.33	260.8	44.4	18,140	1.00
Naruse	11,604	52.05	222.9	25.5	11,714	0.99
Kashimadai	13,956	54.05	258.2	26.8	12,911	1.08
Nango	7,069	39.52	178.9	52.9	7,739	0.91
Total	82,735	264.76	312.5	26.8	72,691	1.14
Sendai City	892,252*4	129.69*4	6,879.9*4	1.3	581,158*4	1.54

*1 The population is estimated based on the resident registers as of the end of June 2003 just before the 2003 Northern Miyagi Earthquake.
*2 The ratio of farmhouses to households is based on the values of the agriculture and forestry industry census in 2000.
*3 The population is based on the final values of the national census in 1975.
*4 Data of the Densely Inhabited District; DID in Sendai City is based on the final values of the national census in 2000.

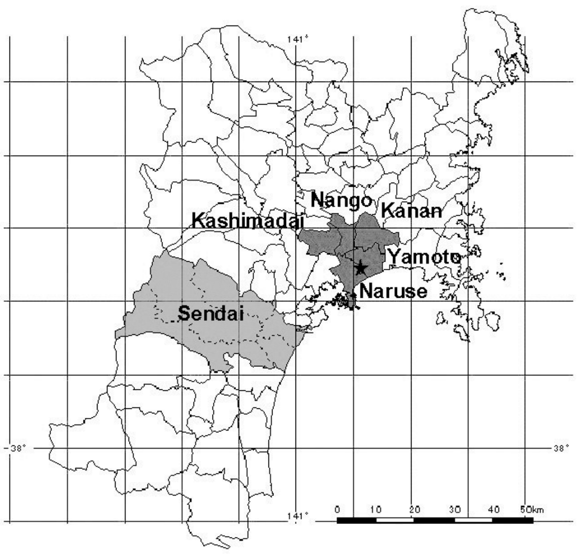


Fig. 1 Location map of the area of damage in Miyagi Prefecture (★: epicenter of mainshock)

2. REGIONAL CHARACTERISTICS

The five towns affected by the earthquake are located in northern Miyagi Prefecture (**Fig. 1**). With numerous clear water rivers such as the Kitakami River, many marshes and a rich landscape, the region has a beautiful natural environment and the main industry is agriculture. The region is affected by earthquakes and flooding.

Social data on the five towns are shown in **Table 1** in comparison with Sendai City. Except Yamoto Town, the population density for the municipal area is approximately 200 people per square kilometer. In Nango and Kanan Town, the occupation of half the households is farming. Excluding Yamoto Town, the population of the five towns has been almost unchanged since 1978 at the time of the Off Miyagi Earthquake. These data show that most areas in the five towns are farmland.

The five towns were incorporated with each other by 2006. Kanan Town was incorporated into Ishinomaki City in April 2005. Yamoto Town and Naruse Town were combined as the new Higashi-Matsushima City in April, 2005. Nango Town and the neighboring Kogota Town were combined as the new Misato Town in January, 2006. Finally, Kashimadai Town was incorporated into Furukawa City and renamed Osaki City in March, 2006. In this paper, evaluation units before the incorporation are used.

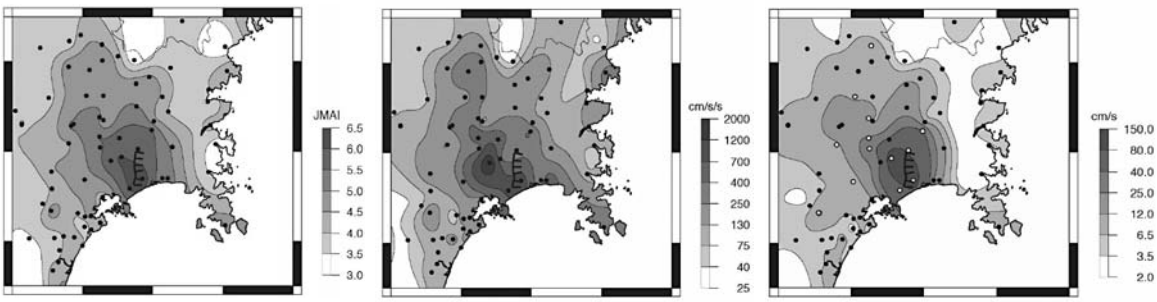
3. STRONG GROUND MOTIONS

A strong shallow earthquake caused severe damage in the region near the epicenter affecting Naruse, Yamoto, Kanan, Nango and Kashimadai Town, where JMA intensity of lower 6 to upper 6 occurred as shown **Table 2**. The distributions of several strong ground motions are shown in **Fig. 2** (Motosaka and Ohno, 2004). The strong ground motion was mainly distributed in the region near the epicenter as shown in **Fig. 2** because of the shallow focus and middle class magnitude. Some large peak ground accelerations were recorded by JMA and local office stations. For example, during the foreshock, Naruse Station at a distance of 3.5 kilometers from the epicenter recorded 2,005 gal as PGA. Unfortunately, most of the strong ground motion records were lost because of overwriting by many aftershock data.

We investigated the tombstones, the turnover monuments and the questionnaire seismic intensity to clarify the earthquake ground motion characteristics as the AIJ Investigation Committee. The results of the questionnaire survey on the seismic intensity in the focal area show that there was an extremely narrow zone reaching an estimated seismic intensity of 7 during the mainshock. The good relationship between measured and estimated seismic intensities in the focal area was clarified (Ochiai, 2004). The questionnaire survey is effective for evaluating the distribution of not only ground motion but also damage. The results were used for analyzing furniture overturning and human injury.

Table 2. List of large amplitude records of five towns

Time	Magnitude (Mj)	Towns	Seismic intensity (JMA scale)	Peak ground motions (gal)		
				NS	EW	UD
00:13	5.6	Naruse	5.9	603	2,005	584
		Yamoto	5.5	366	476	360
07:13	6.4	Yamoto	6.2	667	850	1,242
		Nango	6.0	366	491	193
		Naruse	6.0	636	756	923
		Kashimadai	5.9	1,606	910	497
		Kanan	5.7	337	325	332
16:56	5.5	Kanan	5.7	649	256	499



(a) Seismic intensity (b) PGA (c) PGV

Fig. 2 Distributions of JMA measured seismic intensity, PGA and PGV during the mainshock

4. STRUCTURAL DAMAGE OF BUILDINGS

4.1 Regional characteristics of building structure

We investigated the building damage in the region as the AIJ Investigation Committee. The purpose of the investigation was to clarify the relationship between the earthquake ground motion and the building damage in a statistical way not in individual detail. Shibayama et al. (2005) reported the results of the damage investigation of buildings by earthquake as the AIJ Investigation Committee. In the paper, 93% of the investigated buildings were constructed of wood. The majority of houses were made of wood whereas the majority of public facilities were of non-wooden construction. **Figure 3** shows the classification by the construction age of wooden buildings based on the forecast investigation of earthquake damage by Miyagi Prefecture in 2004. The boundaries of the construction age are set at the time when the seismic design code of buildings was revised. Buildings before 1981 are an object of diagnosis for seismic performance in Japan. In the case of the five towns, wooden structures designed according to the old seismic design code account for approximately 70% in total. This value is slightly higher than those of Miyagi Prefecture and Sendai City.

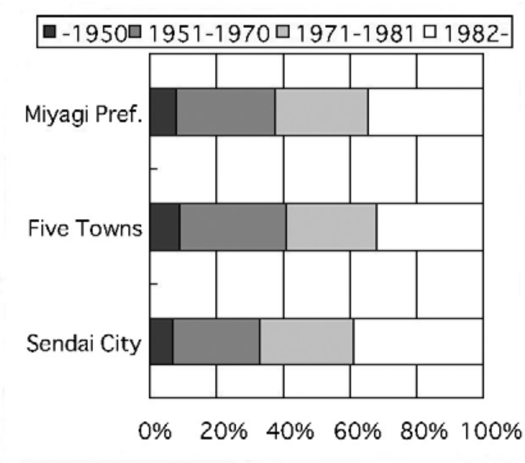


Fig. 3 Classification by construction age for wooden buildings

4.2 Outline of statistical analysis

Most of the houses in the area were made of wood. The number of damaged wooden houses of the five towns as investigated by Miyagi Prefecture is shown in **Table 3**. Here, we define the damage ratio of wooden houses as the sum of damaged houses, including the severely damaged and collapsed houses as one and the moderately damaged houses as half in the total wooden houses. The damage ratio was highest in Naruse Town at 16%. The average in the five towns is approximately 8% with considerable deviations. The damage distribution of wooden houses was limited to a narrow area of the five towns in Miyagi Prefecture.

4.3 Typical examples of building damage

Typical examples of building damage are shown in pho-

Table 3. Counts of damaged wooden houses in Miyagi Prefecture (12 March, 2004)

Towns	Wooden houses*1 (A)	Severely damaged including collapsed (B)	Moderately damaged (C)	Slightly / partly damaged (D)	Damage Ratio (%) (B+0.5C)/A×100
Yamoto	14,289	414	1,295	2,488	7.43
Kanan	9,051	227	409	928	4.77
Naruse	6,126	420	1,211	2,776	16.74
Kashimadai	6,273	53	291	2,599	3.16
Nango	3,910	140	489	1,313	9.83
Subtotal	39,649	1,254	3,695	10,104	7.82
Total	846,443	1,276	3,809	10,975	0.38

*1 Forecast investigation of earthquake damage by Miyagi Prefecture in 2004

Photo. 1 Severely damaged wooden house

Photo. 4 Damage of pilotis structure

Photo. 2 Non-damaged wooden house

Photo. 5 Fallen concrete block

Photo. 3 Collapsed wooden house

Photo. 6 Damage in kitchen

Table 4. Number of injured persons determined by Miyagi Prefecture (2 March, 2004)

Towns	Population*1 <A>	Serious injured <B>	Slightly injured <C>	Total <B+C>	Injured ratio (%) (B+C)/A*100	Seriously injured ratio (%) B/(B+C)×100
Yamoto	32,025	21	395	416	1.30	5.05
Kanan	18,081	3	67	70	0.39	4.29
Naruse	11,604	4	31	35	0.30	11.43
Kashimadai	13,956	2	13	15	0.11	13.33
Nango	7,069	12	53	65	0.92	18.46
Subtotal	82,735	42	559	601	0.73	6.99
Total		51	624	675		

*1 Population based on the basic resident register at the end of June 2003.

tographs taken by the authors. A severely damaged old wooden house is shown in **Photo. 1**. A wooden house that had been designed in line with the new seismic code as shown in **Photo. 2** incurred no damage even though it was near the house in **Photo. 1**. This suggests that the seismic performance differs according to age and design. **Photograph 3** shows a collapsed wooden house constructed in 1920. The light roof of this house had been replaced with heavy Japanese tiles ‘kawara’ without a seismic retrofit of the structural frame. The roof fell whilst maintaining the shape. Structural damage to a wooden house with a soft first story used as a store is shown in **Photo. 4**.

In the focal area, many concrete and stone walls were damaged. Similar damage occurred as a result of the Off Miyagi Earthquake in 1978 causing human casualties. A fallen concrete block wall in a school zone is shown in **Photo. 5**. At the time that the mainshock occurred, most people were assumed to be at home. The ratio of people usually at home based on a life investigation by NHK (2000) is approximately 85%. In the focal area, there were few injuries caused by collapsed block walls. Vulnerable structures should be immediately improved in anticipation of a new off Miyagi Earthquake.

Photograph 6 taken by NHK shows indoor damage to a kitchen in Yamoto Town. The mainshock occurred at breakfast time on Saturday morning, which shows that kitchens as well as bedrooms and living rooms require earthquake preparedness.

Public buildings are generally constructed as reinforced concrete structures of three or four stories. There was only minor damage to the reinforced concrete buildings in the region designed in line with the new seismic code after 1981. Few reinforced concrete buildings designed in line with the old seismic code in the surrounding regions sustained structural damage. Three reinforced concrete buildings of particular interest were Hukaya Hospital, Kitamura Elementary School located in Kanan Town and Kashimadai Hospital in Kashimadai Town.

5. HUMAN INJURIES

5.1 Outline of human injuries

The number of persons injured in Miyagi Prefecture is shown in **Table 4**. As with the concentration of building damage, approximately 90% of injuries were sustained by persons in the five towns. The maximum value in the region exceeded 1% in Yamoto

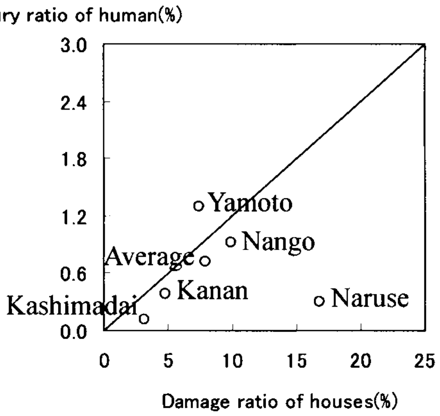


Fig. 4 Relationship between the damaged house ratio and the human injury ratio

Town. Even in the five towns, the human injury ratio was widely different between Yamoto Town and Kashimadai Town. The seriously injured ratio is defined as the ratio of the seriously injured to the total number injured. The average of the five towns was approximately 7%. Because the value is often taken in the range from 5% to 10% for earthquake disasters in Japan, a general result was shown.

The relationship between the damaged house ratio and the human injury ratio is shown in **Fig. 4** with the empirical line based on the Hanshin-Awaji Earthquake Disaster in 1995. The present results correspond closely with those of past earthquake disasters except for those of Naruse Town. The figure shows the human injury ratio when the damaged house ratio is used as an indirect index. The causes of human injury should be noted not only by the damage to houses.

5.2 Causes of human injury

Immediately after the mainshock, the causes of human injury were investigated by NHK and IFD. They obtained data by conducting a hearing survey at hospitals in the region. Each area of the investigation is shown in **Fig.5**. NHK covered a wide area including Sendai City, while the survey of IFD was limited to the management area of Ishinomaki City and nine peripheral towns. There were no injured persons in Onagawa, Ogatsu, Kitakami and

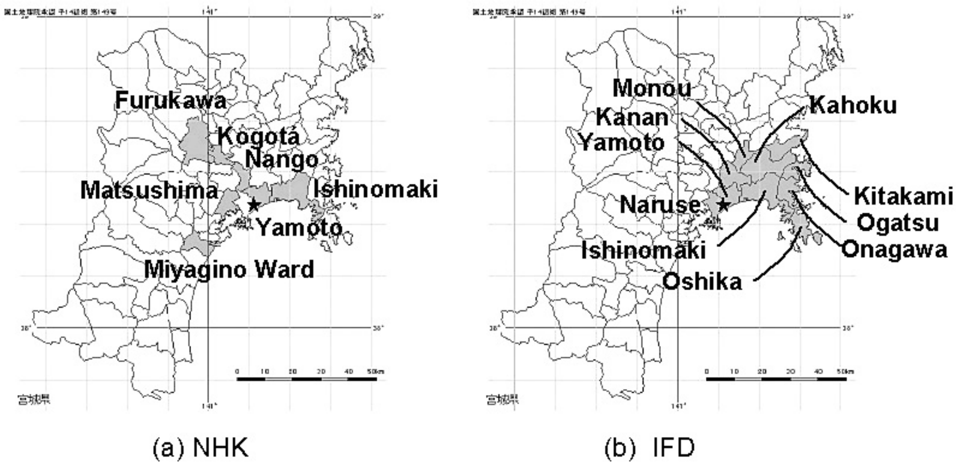


Fig. 5 Area covered by NHK and IFD

Oshika Town. IFD data was almost perfectly collected in the investigation area. However, Nango and Kashimadai Town in the five towns were not included in the area of IFD. NHK data was collected from some hospitals in the investigation area.

By using common items in the hearing survey, the distribution of the major causes were plotted as shown in **Fig. 6**. In the IFD data, furniture overturning has the largest percentage of 35%. NHK data shows objects falling to be the highest cause rather than furniture overturning because the investigation area of the IFD was limited to near the focal area. Furniture overturning and objects falling amount to approximately 50% of the total.

Figure 7 shows injury by age. The young age group is less than 15 years old. The middle age group is from 15 to 64 years old. The old age group is 65 years old or more. In the old age group, the cause by furniture overturning is dominant with the largest percentage of 40%. This indicates that improvement of indoor space by taking measures against falling objects and overturning furniture is the most effective mitigation for human injury especially for vulnerable people such as the young and the elderly.

The injury ratio by age is shown in **Fig. 8**. The IFD data on Yamoto Town was used. The injury ratio increases for older people, reaching 2% for the old age group. This figure also shows the injury ratio by sex. Females have approximately double the injury ratio for all age groups. This tendency occurred in other recent earthquake disasters such as the 2000 Western Tottori Prefecture Earthquake and the 2001 Geiyo Earthquake (Murakami, 2001).

The ratio of injured humans by age is shown in **Fig. 9**. Injuries in the old age group accounts for approximately 40% of the total. This finding indicates that the aging of society will increase the vulnerability to human injury.

Most buildings in the focal area have a one or two story wooden structure because the area is farmland. The seismic motion of the furniture is almost equal to that of the ground surface. But, in an urban area many people would be exposed to high hazard because of the high story buildings and high risk of furniture overturning.

Figure 10 shows injury causes by sex in the old age group. Half the number of causes of injury occurred due to furniture overturning and injuring females in the old age group.

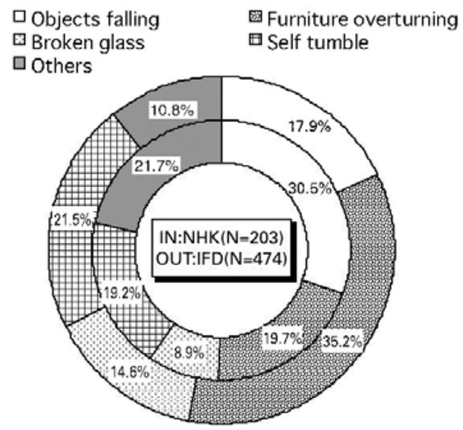


Fig. 6 Main causes of injury

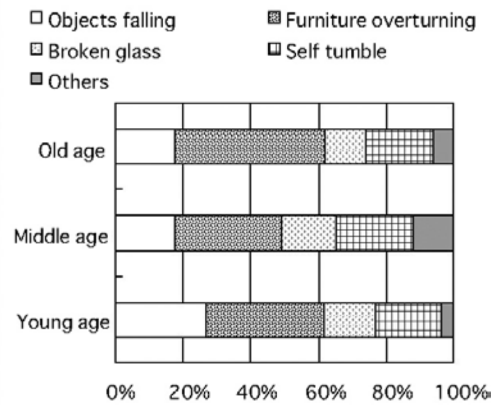


Fig. 7 Contents of injury causes by age

6. DAMAGE INVESTIGATION OF FURNITURE OVERTURNING

6.1 Outline of questionnaire survey

Three months after the event, we conducted a questionnaire survey to determine the seismic intensity and the damage distribu-

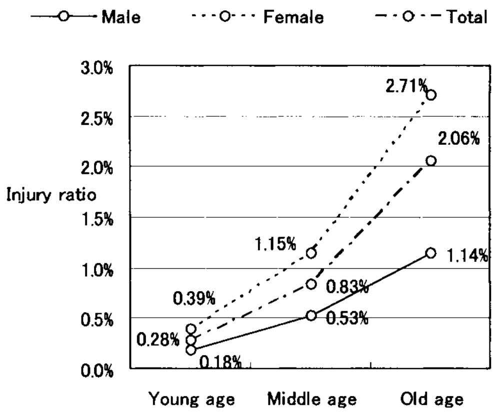


Fig. 8 Ratio of injury by age

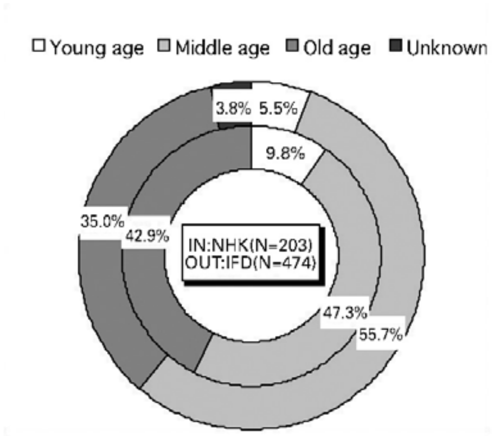


Fig. 9 Injury by age

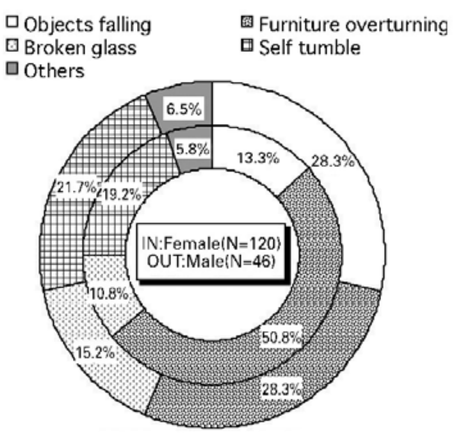


Fig. 10 Contents of injury causes by sex in old age

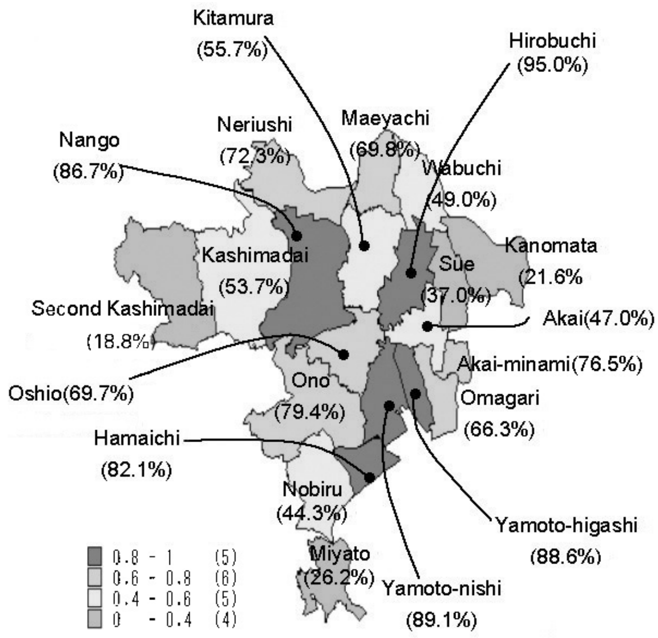


Fig. 11 Distribution of furniture overturning ratio

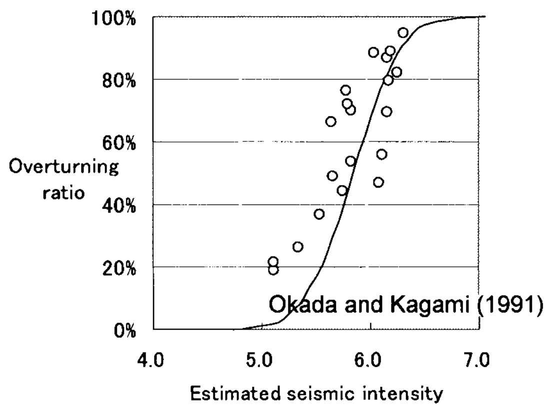


Fig. 12 Fragility curve of furniture overturning

tion with high spatial resolution in the five towns. The survey method revised by Ota et al. was used (Ohta et al., 1998). The questionnaire sheets were distributed to 4,000 households having a pupil at elementary school. The statistics of the questionnaire survey are shown in **Table 5**. The effective collection ratio of the survey was approximately 60% in most towns. The sampling ratio, which is defined as the ratio of the number of effective answers to that of the total households accounts for approximately 10%. The evaluation was conducted for each district of the elementary school.

The distribution of the furniture overturning ratio for each district is shown in **Fig. 11**. The value is defined as the ratio of the total number of house in which furniture overturned to the number of households in which furniture did not overturn. High numbers were recorded in Hirobuchi and Nango districts. The maximum ratio reached 95% in Hirobuchi district. On the other hand, the minimum was 19% in the second Kashimadai district. The ratio sharply decreases by distance from the epicenter.

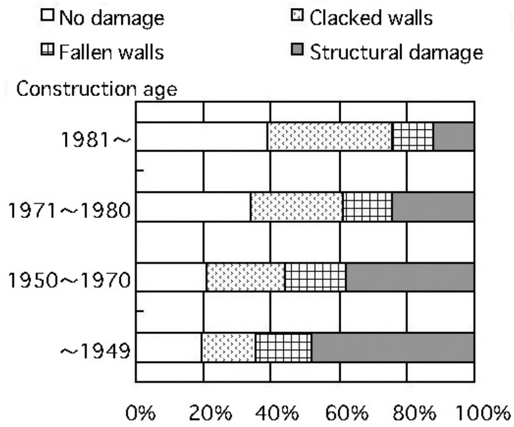
6.2 Fragility curve for furniture overturning ratio

The fragility curve for the furniture overturning is shown in **Fig. 12**. The seismic intensity evaluated by the questionnaire survey is used as a strong ground motion index. In this figure, the Okada and Kagami's relationship (1991) is also plotted. The present results agree with the relationship. The range of the estimated

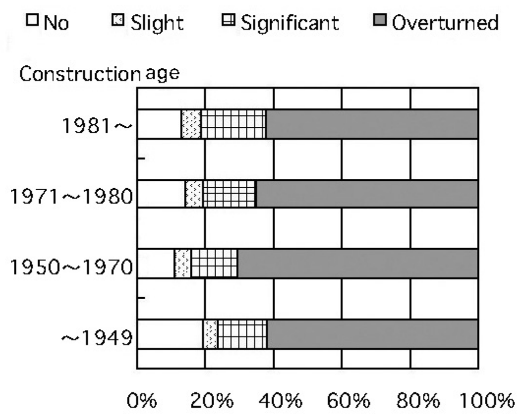
Table 5. Statistics of questionnaire survey

Towns	Households*1 <A>	Number of elementary schools	Number of distributions <B>	Number of effective answers <C>	Effective collection ratio (%) <C/B*100>	Sampling ratio (%) <C/A*100>
Yamoto	10,676	6	1,837	1,037	56.45	9.71
Naruse	3,326	4	560	332	59.28	9.98
Kanan	5,083	6	855	546	63.86	10.74
Nango	1,914	2	310	204	65.81	10.66
Kashimadai	4,218	2	600	342	57.00	8.11
Total	25,217	20	4,162	2,461	59.13	9.76

*1 Households based on the basic resident register at the end of June 2003.



(a) Structural damage ratio



(b) Indoor damage ratio

Fig. 13 Damage ratio distribution of structures and indoors by the age of construction of wooden houses

seismic intensity of 6.5 from 5.5 corresponds with seismic intensity 6 of the JMA scale. In this range, the furniture overturning ratio changes rapidly.

6.3 Relationship between structural and indoor damage

The relationship between structural and indoor damage was analyzed by using the results of the questionnaire survey. The structural damage classified by the house construction age is shown in **Fig. 13 (a)**. In this figure, "cracked walls" and "fallen walls" are defined as damage to the nonstructural elements in wooden houses. The "structural damage" shows damage such as large movement of the structural frame. Structural damage tended to be less for houses of newer construction. Indoor damage classified by the house construction age is shown in **Fig. 13 (b)**. The results of (a) and (b) in **Fig. 13** show quite a different tendency. The indoor damage occurred almost uniformly independent of the house construction age. These data together with the previous observations indicate that in order to mitigate human injury, earthquake preparedness against furniture overturning is necessary even for new houses.

6.4 Investigation for improvement of vulnerability

One year after the event, we investigated the change in vulnerability to earthquake disasters in the focal area. The state of improvement of building structures, and exterior and indoor spaces was investigated by a hearing survey of the households in the region in addition to the questionnaire survey. The results of furniture overturning are shown in **Table 6** and **Fig. 14**. The ratio of earthquake preparedness to prevent furniture overturning reached 25% at maximum before the event. The average in the region was approximately 18% with considerable derivation. In **Fig. 14**, the earthquake preparedness ratio summed up before and after the event is proportional to the furniture overturning ratio. The earthquake preparedness of the region where the furniture overturning ratio was lower had not improved even in the five towns.

This finding suggests that the influence of the disaster lesson decreases according to the distance from the focal area. Administrators and mass communication frequently reminded citizens of the necessity of earthquake preparedness to mitigate human injury caused by furniture overturning, but the effects are insufficient. Interactive risk communication with the residents may be more effective.

7. DISCUSSION

The epicenter was approximately 40 km distant from Sendai

Table 6. Statistics of hearing survey of earthquake preparedness ratio

Towns	District	Sampling number of households <A>	Overturning ratio (%) <B>	Earthquake preparedness ratio (%)		
				Before<C>	After<D>	Total<C+D>
Kanan	Horobuchi	181	85.1	15.6	51.5	67.1
	Hirobuchi(Shinden)	41	65.9	14.6	43.9	58.5
	Kitamura	116	44.8	14.7	25.9	40.5
	Maeyachi	62	67.7	25.8	51.6	77.4
Naruse	Ono	64	64.1	21.9	46.9	68.8
Kashimadai	Kashimadai	43	44.2	14.0	18.6	32.6
Nango	Nango	210	81.9	10.2	46.3	56.6
	Nango(Kojima)	24	87.5	25.0	62.5	87.5
Average			67.6	17.7	43.4	61.1

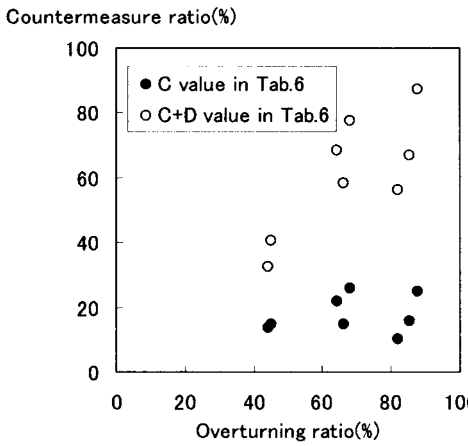


Fig. 14 Relationship between furniture overturning ratio and preparedness one year after the event

City. Sendai City is the biggest city in Tohoku district with a population of one million. The damage to Sendai City was negligible during the 2003 Northern Miyagi Earthquake, because the maximum seismic intensity in Sendai City was lower than 5 on the JMA scale.

In the case of a densely inhabited districts in Sendai City, the population has increased more than 50% since the previous Off Miyagi Earthquake in 1978. But the lessons of the 2003 Northern Miyagi earthquake are extremely valuable when determining disaster measures for the next off Miyagi earthquake in Sendai City. Even if the next of Miyagi earthquake is similar to the previous earthquake in 1978, the situation of earthquake damage due to changes in the social environment between periodically repeated times is very different. For example, the number of households in Sendai City doubled since the previous earthquake, which occurred 28 years ago. There were only about 50 apartment buildings of more than 10 stories in Sendai City in 1978. Now there are ten times as many of such buildings. The number of people exposed to high hazard such as the strong floor response in an indoor space has increased. Human injury due to structural damage to the building tends to decrease, because the building structures have been strengthened through revision of the building code. The potential for human injury is increasing in urban areas such as Sendai City.

8. CONCLUSIONS

The main conclusions obtained are as follows.

(1) The 2003 Northern Miyagi Earthquake was outlined and some typical examples were shown.

(2) The causes of human injury and the age and sex ratios were analyzed based on data from five towns as the focal area. The results show that furniture overturning is the main cause of injury.

(3) The furniture overturning ratio based on the questionnaire survey was evaluated. The present results agree with past relationships.

(4) Indoor damage occurred almost uniformly independent of the construction age. These data together with the previous data suggest that for the mitigation of human injury, earthquake preparedness against furniture overturning is necessary even for new houses.

(5) One year after the event, the results of the hearing survey show that the earthquake preparedness of regions where the furniture overturning ratio was lower has not improved even in the five towns.

(6) The potential for human injury caused by furniture overturning is increasing because the population exposed to high hazard such as the strong floor response in indoor spaces has increased.

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REFERENCES

Kagami, H., 2005. Literature survey on previous earthquake damages at the affected area of the Northern Miyagi Earthquake of July 26, 2003, *AIJ Journal of Technology and Design*, 21, 401-404. (In Japanese)

Motosaka, M. and Ohno, S., 2004. Ground motion records and their characteristics, *Report on the damage investigation of the July 26. 2003 Northern Miyagi Earthquake*, 166-170. (In Japanese)

Murakami, H., 2001. Human casualties, its causes and distribution, *Report on the damage investigation of the 2000 Western Tottori Prefecture Earthquake and the 2001 Geiyo Earthquake*, 184-187, 363-366. (In Japanese)

Ochiai, M., Motosaka, M., Ohno, S. and Sato, T., 2004. A questionnaire survey for estimating seismic intensities in and around focal area, on the July 26. 2003 Northern Miyagi Earthquake, *Tohoku Journal of Natural Disaster Science*, 40, 83-88. (In Japanese)

Ohta, Y., Koyama, M. and Nakagawa, K., 1998. Revision of Algorithm for Seismic Intensity Determination by Questionnaire Survey -In High Intensity Range-, *Journal of Japan Society for Natural Disaster Science*, 16-4, 307-323. (In Japanese)

Okada, S. and Kagami, H., 1991. Inventory Vulnerability Functions for Earthquake Damage Evaluation in terms of Intensity Scale of the Japan Meteorological Agency, *Journal of the Seismological Society of Japan (Second edition)*, 44, 93-108. (In Japanese)

Shibayama, A., Sato, T., Murayama, Y., Hirano, S., Matsumoto, H., Masuda, S., Hisada, Y. and Motosaka, M., 2005. Damage investigation of building in the 26 July 2003 Northern Miyagi Prefecture Earthquake, *AIJ Journal of Technology and Design*, 22, 595-600. (In Japanese)

The NHK Broadcasting Culture Research Institute, 2001. *NHK DaTableook 2000 National Time Use Survey (Prefectural edition)*, 84-101. (In Japanese)