HUMAN CASUALTY AND DAMAGE DISTRIBUTION IN RELATION TO SEISMIC INTENSITY IN THE 2006 CENTRAL JAVA EARTHQUAKE IN INDONESIA

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ABSTRACT :

The 2006 Central Java (Jogyakarta) earthquake occurred on May 27, and caused 140 thousand dwellings collapsed 190 thousand dwellings heavily damaged, and 5,800 human lives lost. The authors made reconnaissance field survey in June, 2006, collected damage statistics and examined GIS distribution. The seismic intensities were estimated by means of questionnaire survey. Obtained results are as follows.
(1) Dwelling collapse rate reached 60% and human loss rate exceeded 1.6% along 20km in NNE direction around epicenter. Human loss rates tend to be smaller for the similar levels of dwelling collapse rates in Java where single story dwellings are common, than in the 1995 Kobe earthquake region.
(2) Maximum MSK intensity of 8 or larger is estimated in the epicenter area, while it decreases toward the west direction. Probability of human casualty increases while dwelling damage levels worsened and human loss occurred in approximately 12% of households, when a single wall collapsed or two or more walls totally collapsed.
(3) Comparison of building types in damage levels indicated that brick houses are more vulnerable than RC buildings and wooden houses. At MSK intensity 8, responses of many brick houses collapsed reaches 0.77 and the highest, while that of RC buildings is 0.44 and that of wooden houses is 0.11.

KEYWORDS: seismic intensity, building vulnerability, human loss, Java earthquake

1. INTRODUCTION

The 2006 Central Java Earthquake with magnitude 6.3 occurred on Saturday May 27th at 5:53 a.m., local time, or Friday, May 26, 2006 at 22:53:58 (UTC) in Bantul district of Yogyakarta Special State, Indonesia (USGS, 2006). Dwelling damages and human casualty were very severe affecting densely populated farming villages and towns in the State and also urban area of Yogyakarta city. The authors conducted field reconnaissance survey joining a team of Kyushu University in June, 2006. This study aims to elucidate dwelling damages vulnerability and human casualty in relation with seismic intensity and other factors.

2. GIS DISTRIBUTION OF DAMAGE BASED ON STATISTICS

2.1. GIS Distribution of Damage and Human Loss

According to the report by the Indonesian Government Disaster Management Center, total human casualty numbered 5,778 people killed and 37,883 people injured, while dwelling damage numbered 139,859 dwellings totally collapsed and 190,025 dwellings heavily damaged. The area affected by this earthquake is the special state of Yogyakarta and Klaten district, which belongs to Central Java State. GIS files for the affected area, which contains ARC-GIS shape file layers of polygons are used to map damage distribution.
We collected damage statistics of dwelling damage and human casualty in sub-district or village levels by visiting district or sub-district offices. Dwelling damage and human casualty were investigated officially at

village levels and were reported to sub-districts, to districts, to provinces and to the central government thru administrative hierarchy. Dwelling damage levels in Java were classified into 4 levels as follows; total collapse, heavy damage, moderate or light damage and apparently no damage. In case of MSK seismic intensity definition, building damage levels are classified into 5 as follows: Grade 1 slight damage, Grade 2 moderate damage, Grade 3 heavy damage, Grade 4 destruction, Grade 5 total damage. Total collapse Java may be regarded as corresponding to Grade 4 and 5, heavy damage to Grade 3, and moderate or light damage to Grade 1 and 2.

Table 2.1 indicates district-wise damage and human casualty statistics reported by the Indonesian national government. Bantul district suffered by far the heaviest damage with 0.5% human loss, while Klaten district followed with 0.09% human loss. According to the National Population Census in 2000, average household members are 3.4 person / household in Jogyakarta Special Province and 4.0 person / household in Central Java Province. Percentage of urban population is 57.7% in Jogyakarta Special Province, while it is 40.4% in Central Java State.

Table 2.1 Damage statistics reported by Indonesian Government as of June 27, 2006

Province	District	Population (1000s)	Dead	Injured	Refugee	Completely destroyed	Heavily damaged	Slightly damaged	Dead/Population
Jogjakarta Special Province	Bantul	823.4	4,143	12,026	778,251	71,763	71,372	73,669	0.50%
	Sleman	955.2	246	3,777	153,596	19,113	27,687	49,065	0.03%
	Kulon progo	386.8	24	2,179	205,625	4,685	8,430	9,672	0.01%
	Jogjakarta	419.2	218	313	74,592	6,085	5,408	15,364	0.05%
	Gunung Kidul	695.7	84	1,086	140,012	7,454	11,033	27,218	0.01%
	TOTAL	3280.2	4,715	19,381	1,352,076	109,100	123,930	174,988	0.14%
Central Jawa Province	Klaten	1139.2	1,045	18,127	713,788	29,988	62,979	98,552	0.09%
	Boyolali	941.7	4	300	12,770	307	696	708	0.00%
	Magelang	1158.1	10		5,108	386	386	546	0.00%
	Purworejo	712.1	1	4	9,806	10	214	780	0.00%
	Sukoharjo	838.3	3	67	16,302	51	1,808	2,476	0.00%
	Wonogiri	1010.6	0	4	2,022	17	12	74	0.00%
	TOTAL	32900.0	1,063	18,502	759,796	30,759	66,095	103,136	0.00%
	GRAND TOTA	45260.5	5,778	37,883	2,111,872	139,859	190,025	278,124	0.01%

damage: http://www.bakornaspbp.go.id/html/buletindijjateng.htm
population: the National Population Census in 2000, after BAPPENAS (2006), Source: Data BPS Data Dan Informasi Keminiskan (2004)

Figure 2.1 shows damage distribution obtained by UNOSAT and epicenters. Figure 2.2 shows dwelling damage and fatality distribution using sub-district-wise statistics. Pleret, Jetis, and Pundong sub-districts of Bantul district are in concentrated high damage zone over 60% of collapse ratio extending from NNE to SSW for approximately 20km. Gantiwarno and Wedi sub-districts located in the southern parts of Klaten district depict 30-60% total collapse ratio, which agrees with our field observation. Damage distribution agrees well with UNOSAT (2006) early estimation on their web-site after the earthquake (Fig. 2.1). The earthquake source locations estimated using Real-time-JISNET data by Nakano et al. (2006) agree with the severe damage zone in Fig. 2.2. High damage zone extends to north to Sleman district, in the east of Jogjakarta (Yogyakarta) city. Human loss distribution in Figure 2.2 indicates similar pattern as the dwelling collapse ratio. Human loss ratio in Pleret, Jetis, and

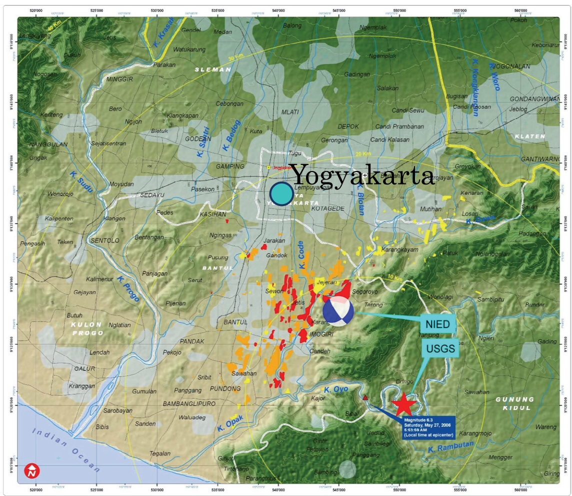


Figure 2.1 Damage distribution obtained by UNOSAT[1] and the location of the epicenter by USGS[2] and the mechanism of the moment centroid by NIED[3] (after Kawase, et al., 2006)

Pundong sub-districts reach 0.8% to 1.6% and that concentration extends approximately 20km along the NNE to SSW direction.

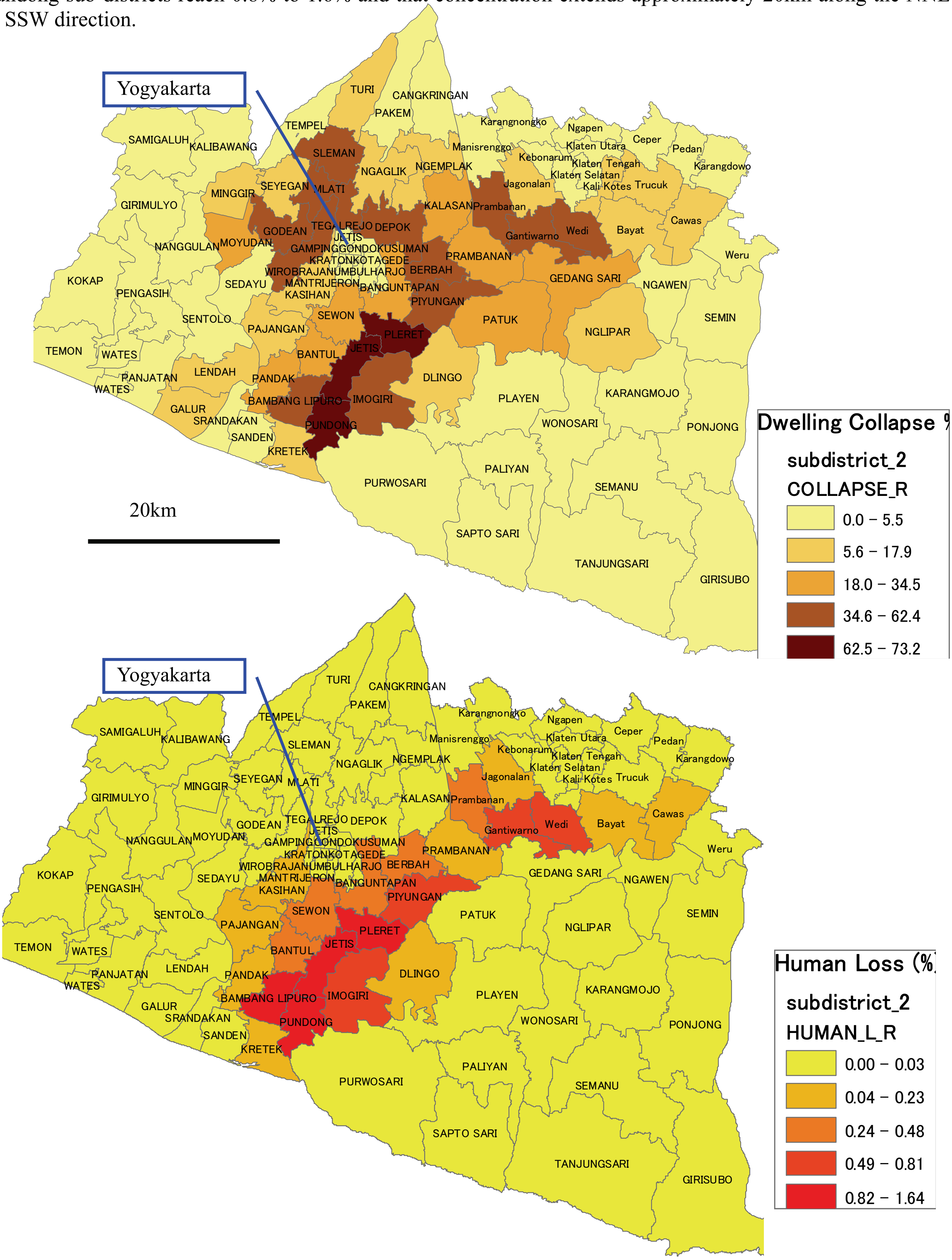


Figure 2.2 GIS distribution of dwelling collapse rate (%) above and human loss rate (%) below using sub-district damage statistics data.

2.2. Relation of dwelling collapse and human loss

Figure 2.3 shows the relation between rate of dwellings totally collapsed and rate of human loss for village statistics in Bantul District. Normal correlation is obvious with correlation coefficient R=0.896 and human loss rate further increases while total collapse rate exceeds 60%. Linear regression equation is obtained as follows.

$$FR = 0.023\ CR - 0.17 \qquad (2.1)$$

where FR: Fatality Rate (%),
CR: Dwelling Collapse Damage Rate (%)

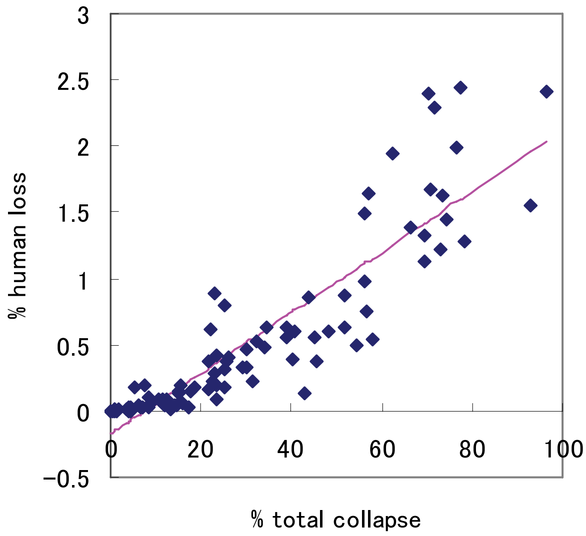


Figure 2.3 Relation of total collapse % and human loss % in the Java earthquake

Based on the damage report of the 1995 Kobe earthquake by Fire Research Institute of Japan, the following relation between dwelling heavy damage rate and human loss rate is given for earthquake damage estimation manual (Fig. 2.4).

$$FRW = 0.0359 \times CHR \qquad (2.2)$$

where FRW: Fatality Ratio in Wooden Buildings (%)
CHR: Wooden Dwelling Collapse and Heavy Damage Ratio (%)

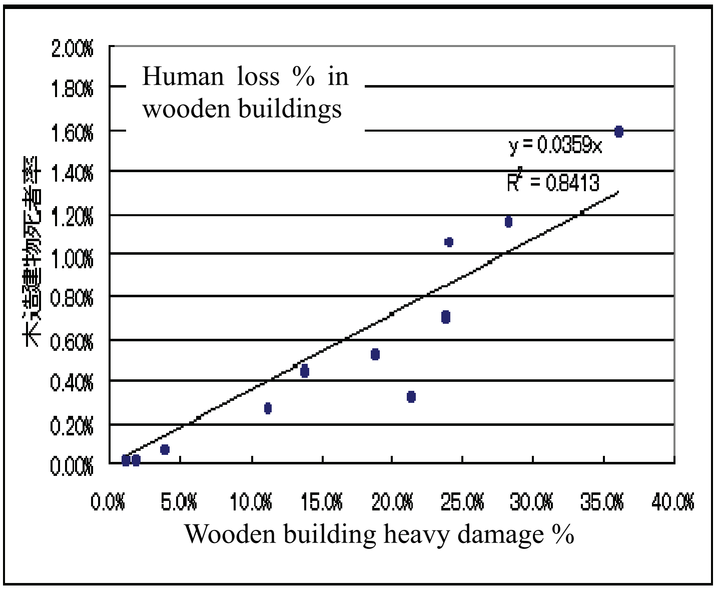


Figure 2.4 Relation of dwelling heavy damage rate (%) and human loss rate (%) for the 1995 Kobe earthquake (Disaster Mitigation Division of Cabinet Office, Japan).

For the same levels of dwelling damages, fatality ratio in Java is approximately half of that in the Kobe earthquake, probably because single story dwellings are majority in Java, while two story dwellings were common in Kobe. In Central Java, more two story dwellings have been constructed along urban sprawl and economic development of the area. It is very important to provide education and training of dwelling earthquake safety (seismic resistance) for local residents (home owners) and carpenters, otherwise we are afraid that human casualty could be doubled in future earthquakes.

3. SEISMIC INTENSITY ESTIMATION BY QUESTIONNAIRE SURVEY

3.1. Survey Method

In order to estimate strength of seismic shaking in the disaster area, we conducted questionnaire survey of seismic intensity. The author (H.M.) made the questionnaire based on MSK intensity scale definition and utilized for the field reconnaissance survey of the 2001 Gujarat, India earthquake (Murakami, 2001). Out of the 26 questions, 16 are used to estimate seismic intensity as indicated in Table 3.1. Based on the 12 scale MSK seismic intensity definition, each item category is given a respective intensity coefficient in the form of fuzzy membership functions, corresponding to likelihood of seismic intensity.

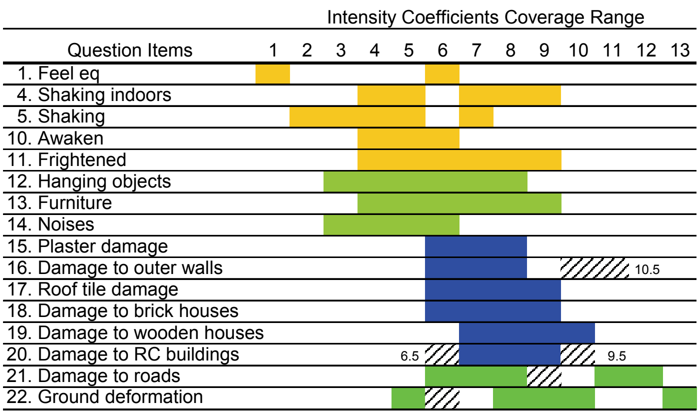
Table 3.2 Locations where intensity questionnaire survey was conducted along Pleret, Imogiri, and Klaten observation lines and MSK intensities estimated

	Loc. No.	Code	No. effective data	MSK intensity (mean)	MSK intensity (st.dev)	Subvillage DUSUN	Village DESA	Sub-district KECAMATAN	District KABU-PATEN	Epic. Dist ** (km)
Pleret obs. line	Loc03	KEDUN	8	8.2	0.2	Kedungpring	Bawuran	Pleret	Bantul	1.8
	Loc04	TEGAL	9	9.1	1.5	Tegalrejo	Bawuran	Pleret	Bantul	1.8
	Loc02	KAUM	3	8.5	0.3	Kauman	Pleret	Pleret	Bantul	2.5
	Loc01	WONO	4	7.0	1.0	Ketonggo	Wonokromo	Pleret	Bantul	3.1
	Loc05	PACAR	10	8.8	1.2	Bibis	Timbulharjo	Sewon	Bantul	3.9
	Loc06	KOWEN	4	7.8	0.5	Kowen II	Timbulharjo	Sewon	Bantul	5.5
	Loc07	MELIK	3	7.5	0.3	Gandekan	Bantl	Bantul	Bantul	8.8
Imogiri obs. line	Loc08	KARAN	7	8.4	1.4	Mojohuro	Sriharjo	Imogiri	Bantul	4.8
	Loc09	SRIHA	0	-	-	Minggiran	Imogiri	Imogiri	Bantul	7.3
	Loc10	MANGG	8	7.4	0.7	Maggung	Wukirsari	Imogiri	Bantul	3.7
	Loc11	PULOK	8	8.3	0.6	Pulokadang	Canden	Jetis	Bantul	5.3
	Loc12	BAKUL	8	7.7	0.6	Bakulan	Patalan	Jetis	Bantul	7.2
	Loc13	PENI	5	7.9	0.6	Peni	Palbapang	Bantul	Bantul	8.9
	Loc14	GILAN	3	7.7	0.1	Srandakan Ka	Gilangharo	Pandak	Bantul	10.9
Klaten obs. line	Loc16	CUCUK	10	7.9	0.6	Gupala	Cucukan	Prambanan	Klaten	18.3
	Loc17	MLESE	9	8.2	0.7	Mlese	Mlese	Gantiwarno	Klaten	20.6
	Loc18	PASUN	10	8.0	0.3	Jabung	Jabung	Gantiwarno	Klaten	23.8
	Loc19	JABUN	8	8.0	0.5	Pasung	Pasung	Wedi	Klaten	22
	Loc20	NGAD	0	-	-	Jenon	Ngandong	Gantiwarno	Klaten	19
Survey by R. Ohno	Loc21		16	7.0	0.4		Purbayan	Kotagedhe	Yogyakart	6.9
	Loc22		16	6.9	0.4	Payaman Uta	Girirejo	Imogiri	Bantul	4.4
	Loc23		16	8.1	1.1		Segoroyoso	Pleret	Bantul	1.1
	Loc24		15	8.5	1.5	Tegalrejo	Bawuran	Pleret	Bantul	1.8
	Loc25		16	7.3	0.2	Bungasan	Karangturi	Gantiwarno	Klaten	22
	Loc26		16	7.3	0.4		Kaligayam	Wedi	Klaten	25.5
Total			212							

*: Address of each respondent was examined and effective data for each village were selected.
** Distance from Epicenter (7.89 deg.S, 110.41 deg.E, depth 10km, by Nakano, M. et al. (2006))

The previous questionnaire was revised considering common dwelling types and living environment in the Central Java region and was translated to Indonesian and Javanese language. The questionnaire of 4 page long contains 26 questions, in which 6 ask location and dwelling type at the time of earthquake occurrence, 8 ask intensity of shaking by observation of people, hanging objects and furniture, 6 ask building damages, 2 ask road damage and ground failure, 2 ask entrapment and human casualty of oneself or family members, 2 ask personal attributes.

Table 3.1 Intensity coefficients covered by different question items and categories



In the field reconnaissance, four senior students in the Department of Architecture and Planning, Gadjah Mada University worked as interviewers for three days. The students met villagers and local people evacuating and asked questions of the seismic intensity form. Prof. Kawase made microtremor observation on the ground of elementary schools along Prelet, Imogiri, and Klaten observation lines that is EW direction and transverse to the fault line. The intensity questionnaire survey was conducted at the same locations. Altogether, 150 questionnaire responses were obtained covering 17 locations as indicated in Table 3.2.

Ohno, R. et al. (2007) conducted interview survey for human response during and after the earthquake and recovery and reconstruction process of the affected people in November and December, 2006. They made seismic intensity survey using the same questionnaire. Table 3.2 includes their survey results. The effective intensity questionnaire data collected are 212 cases from 23 locations.

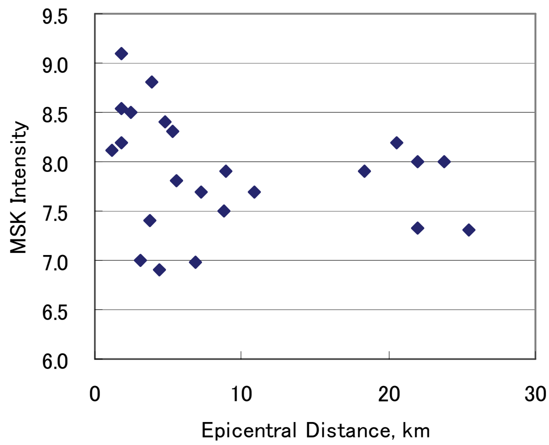


Figure 3.1 MSK intensity vs. epicentral distance.

32. MSK Seismic Intensity Estimated

Seismic intensity for each questionnaire is estimated using fuzzy set intensity coefficients and mean value for each location is obtained (Table3.2). Standard deviation is 0.7 or less for 17 locations, while it exceeds 1.0 for 6 other locations. The table indicates also epicentral distances measured using epicenter decided by Nakano et al (2006), that is, Latitude 7.89 deg S, and Longitude 110.41 deg E. For Pleret and Imogiri observation lines, estimated seismic intensities are around 8.6 and are largest at the far east village of Bawuran, which seems to be the nearest to the epicenter. The seismic intensities decrease from east to west and are 7.5 to 7.7 around Bantul city in the western most location. Seismic intensities of Gantiwarno and Wedi in Klaten district are around 7.9 to 8.2, where dwelling damages were severe.

MSK intensity vs. epicentral distance is plotted in Fig. 3.1. Intensities attenuate from the epicenter to 10km distance, though they are largely scattered, probably due to the effects of source and local soil conditions. Villages at around 20km epicentral distance are located in Klaten district and they show high intensities.

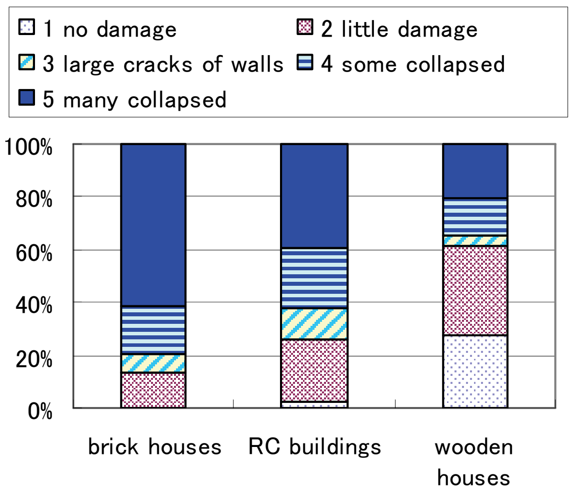


Figure 3.2 Comparison of damage levels of dwellings in your neighborhood among brick houses (Q18), wooden houses (Q19), and RC buildings

3.3. Building types and seismic vulnerability

Structural types of buildings one was located at the time of the earthquake, that is, mostly dwellings (Q6) are brick masonry (21%), half timber and masonry (37%), wood (15%), and RC frame (27%). It seems that not many respondents actually live in traditional type of timber frame dwellings. As for the number of stories, 97% answered single story, while 3% answered two stories. Locations at the time of earthquake occurrence are inside (71%), outside (28%), and in a vehicle (1%). Those who were awake before the earthquake occurrence are 66%. Movement of furniture in rooms indicates that most fell (39%), many moved and some fell (24%). Wall damages of a building one was located suggest severe damage levels as a single wall collapsed (19%), and two or more walls collapsed (41%).

Figure 3.2 shows comparison of the damage levels of different types of dwellings or buildings in the neibourhood (Q18, Q19, and Q20). Damage categories in Fig. 3.1 may correspond to official damage statistics as follows; 2. little damage corresponds to slightly or moderately damaged, 3. large cracks of walls and 4. some collapsed correspond to heavily damaged, and 5. many collapsed corresponds to completely destroyed. It clearly indicates that brick masonry suffered heaviest level of damage with most collapsed, followed by RC dwellings and by wooden dwellings. In case of wooden dwellings, responses of large cracks of walls count few, suggesting there were either no damage or serious damage. If wooden dwellings mean traditional type of timber frame with woven bamboo wall panels, they are not likely to suffer many cracks. We may need more information regarding damage patterns of traditional timber frame dwellings, however, it is very important that traditional timber frame dwellings with bamboo net wall panels and light tile roofing are lighter in weight than masonry dwellings and are reasonable to be more seismic resistant and are less lethal to the occupants even when heavily damaged. Construction method and damage characteristics of traditional timber dwellings are described by Ohno et al. (2006).

Figure 3.3 shows relations of human casualty of family members against the damage levels of dwellings. Entrapment probability significantly increases while damage level reaches to large cracks and partial wall collapse and it reaches to 60% in case of total collapse of a dwelling. In the same manner, human casualty increases as wall damage deteriorates and human loss occurred in approximately 12% of households, when a single wall collapsed or two or more walls totally collapsed.

Using the intensity questionnaire data, rate of "many collapsed" response for brick, wooden, and RC dwellings are plotted vs. MSK intensity of the locations (Fig. 3.4). It is clearly observed that brick houses suffered highest rate of collapse, while RC buildings and wooden dwellings follow with lower rates of collapse. Data plotted in Fig. 3.3 are divided into MSK levels and average ratio of people who observed many of houses or buildings of each type collapsed are indicated in Table 3.3.

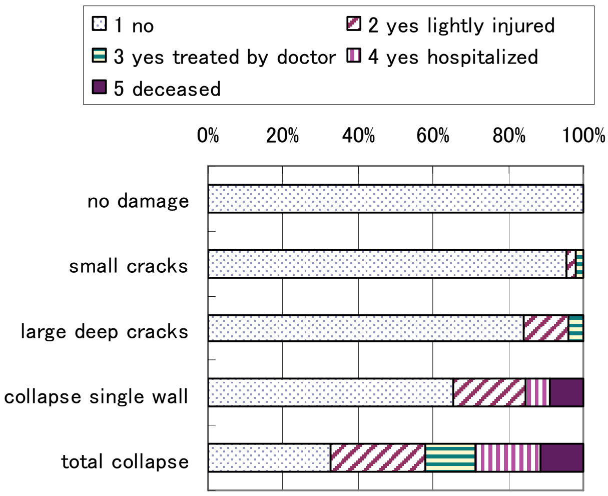


Figure 3.3 Casualty of family members in relation to the damage levels of dwellings according to the questionnaire data.

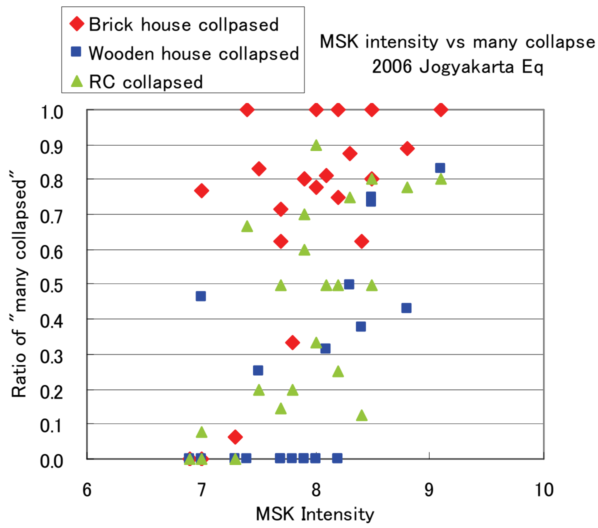


Figure 3.4 MSK intensity vs. rate of "many collapsed" response to neighborhood dwellings.

Table 3.3 Average ratio of people who observed many of houses or buildings of that type collapsed.

	MSK 7	MSK 8	MSK 9
Brick houses	0.32	0.77	0.92
RC	0.12	0.44	0.72
Wooden houses	0.08	0.11	0.69
No of locations	6	13	4

4. CONCLUDING REMARKS

We made GIS maps to indicate distribution of dwelling collapse rate and human loss rate and clarified that there is intensive damage zone extending for 18km in NS direction along Prelet, Jetis, and Pundong sub-districts with total collapse rate over 60% and human loss rate over 1.6%. Fatality rate against dwelling collapse rate in Java is approximately half of that in Kobe earthquake, possibly because single story dwellings are the majority in Java while many two story dwellings in Kobe were collapsed.

Seismic intensity survey by questionnaire method was conducted during the field reconnaissance and intensity was estimated using fuzzy set intensity coefficients based on MSK intensity definition. It was found that damage levels of brick masonry dwellings are severer than RC dwellings and wooden dwellings in the same neibourhood suggesting traditional timber frame dwellings are lighter and more earthquake resistant. Probability of entrapment and casualty of oneself or family members clearly increases along damage level of dwellings. Twelve % of human losses in households were observed in case of total collapse with two or more walls collapsed.

Study results indicate that traditional timber frame dwellings sustained less collapse and damage than brick houses in this earthquake. However, many people seem still prefer to reconstruct brick houses due to modern and urban image, security, easy maintenance and/or availability of building materials. It is very important to extend education and training how to build earthquake resistant houses to people and local home builders in recovery and restoration stages.

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