A STUDY ON DAMAGED BUILDING DATA OF THE 1995 HYOGO-KEN-NANBU EARTHQUAKE

Masayuki KOHIYAMA[1], Kaoru MIZUKOSHI[2], Hiroshi ISHIDA[3], Kazuaki TORISAWA[4] And Tsunehisa TSUGAWA[5]

SUMMARY

Fragility functions of buildings, which show the relation between seismic intensity and building damage ratio, are used for estimation of building damage caused by an earthquake. Fragility functions are formulated statistically by data of seismic intensity and building damage ratio on cell units and area size of the cells should be considered to calculate damage ratios. In this paper, the characteristics of damage ratio data are discussed using GIS (geographic information system) data of buildings damaged by the 1995 Hyogo-ken Nanbu Earthquake. First, the two databases of the different parties, which concerns buildings damaged by the earthquake, were compared in terms of the method of each survey and their criteria of damage ranking. It was found that the criteria of damage ranking of the two databases do not differ much, but numbers of damaged buildings and the damage ratios in each rank differ remarkably from each other. Secondly, based on the damage ratios in terms of various cell sizes, it is pointed out that the adequate cell size ranges from 10,000 m^2 to 200,000 m^2 from the viewpoints of the number of target buildings in the unit and the resolution of the damage distribution.

INTRODUCTION

After the 1995 Hyogo-ken Nanbu Earthquake, various parties surveyed damaged buildings covering afflicted area widely (e.g., AIJ&CPIJ, 1995; GSI, 1995; Kinki Chapter of AIJ, 1995; FIT of Kobe Univ., 1995). Some of those survey results are released as GIS (geographic information system) data and available to many researchers (e.g. FIT of Kobe Univ., 1995; BRI, 1996). In the complete enumerations, from which surveys are of all buildings in wide quake areas, damaged buildings are categorized to several ranks. When using multiple databases, it is necessary to analyze correlation of corresponding ranks qualitatively (e.g. Miyakoshi et al., 1997; Hasegawa et al., 1998; Murao and Yamazaki, 1998) and it is also necessary to investigate distributions of building damage ratios for each database. BRI (1996) made cross-counting analyses of survey results and studied the relations between ranks of different databases. Murao and Yamazaki (1998) compared the results of surveys by AIJ&CPIJ and those by Ashiya City for each region and studied the relations between ranks. In addition, damage ratio distribution should be studied for different aggregation units of damage databases.

On the other hand, fragility functions, which relate seismic intensity to building damage ratios, are often used to estimate building damage in urban area. Evaluation methods are divided roughly into two ways. One is a statistic method using building damage data and observed earthquake motions (e.g. Miyakoshi et al., 1997; Hasegawa et al., 1998; Murao and Yamazaki, 1998; Kashima et al., 1996; Tong et al., 1994). The other is a simulation method using building models for earthquake response analyses (e.g. Shibata and Akamatsu, 1988). In the former method, aggregated data in a region, which has a certain area, and a seismic intensity, which represents the earthquake ground motion in the region, are used generally. In this case, the seismic intensity is affected by erratic pattern of the earthquake ground motion in the region. Though Tagashira (1990) and Aoki (1998) pointed

1 *Earthquake Disaster Mitigation Research Center, Japan E-mail: kohiyama@miki.riken.go.jp*
2 *Kajima Technical Research Institute, Chofu, Japan Fax: +81-424-89-7184*
3 *Kajima Technical Research Institute, Chofu, Japan Fax: +81-424-89-7184*
4 *Kajima Technical Research Institute, Chofu, Japan Fax: +81-424-89-7184*
5 *Kajima Technical Research Institute, Chofu, Japan Fax: +81-424-89-7184*

out the necessity of setting an adequate area to aggregate data when dealing with spatially distributed data, there has not been the sufficient discussion for analysis of widely distributed building data damaged by an earthquake.

This study is oriented to grasp characteristics of damage ratio data as a basic study to evaluate a fragility function. Available databases of buildings damaged by the 1995 Hyogo-ken Nanbu Earthquake are compared and fluctuation of damage ratio distribution is studied for various aggregation units.

COMPARISON OF DAMAGED BUILDING DATA

Comparison of Surveys of Damaged Buildings

In this study, buildings damaged only by earthquake ground motion are target and those burned by earthquake-triggered fire are not included. Followings are building damage databases used in this study.

- Data-K: GIS database compiling results of the survey by Field Investigation Team on Great Hanshin Earthquake, Department of Civil Engineering, Faculty of Engineering, Kobe University [FIT of Kobe University, 1995]

- Data-B: GIS database issued by Building Research Institute of Japan [BRI, 1996], compiling results of the survey by Architectural Institute of Japan and City Planning Institute of Japan [AIJ&CPIJ, 1995]

- Data-G: the Disaster Map of the 1995 Hyogoken-Nanbu Earthquake (2nd Edition) issued by Geographical Survey Institute of Japan [GSI, 1995]

Outlines of these databases are shown in Table 1. Both Data-B and G are created based on the results of the surveys of AIJ&CPIJ and Hyogo Prefecture. The total number of buildings in Data-B may be accurate because non-polygonized data are counted as buildings of unknown damage. In the Data-K, undamaged buildings are not counted. Criteria of damage ranking for Data-K, B and G are shown in Table 2. While Data-K is ranked by residence status, Data-B is ranked based on usability. Therefore, the ranks of Data-K and B may not correspond because of different viewpoints of inquirers.

Quantitative Comparison of Aggregated Data

The Criteria of damage ranking for Data-B and K are compared in this section. A comparison of Data-B and G is omitted because both databases are based on the surveys of AIJ&CPIJ and Hyogo Prefecture. The target area of the comparison is the area that was surveyed by FIT of Kobe Univ. and included in Kobe City as shown in Figure 1. While Data-B is aggregated by blocks and neighborhood units (*cho-chome*), Data-K consists of building polygons. Therefore, Data-K is aggregated by those two kinds of units to compare two databases. Number of units and buildings for those two kinds of units are shown in Table 3. The difference of total number of buildings comes from the difference of target region. In this study, only completely included blocks or neighborhood units are considered and the total areas of those units differ slightly. Damage ratios are defined in this study as shown in Table 4. As Data-K does not have undamaged building polygons and total numbers of buildings in units are unknown, the total numbers of Data-B are used in order to calculate damage ratios of Data-K. The damage ratios of two databases are analyzed by weighting least square method. The regression line is expressed in the formula

$$Y = a + b\,X \tag{1}$$

in which X and Y are a damage ratio of Data-B and that of Data-K, respectively. Weighting factors are adopted with denominators in definition of damage ratios for Data-B, considering reliability of the damage ratios depends on the denominators. The results of regression analyses are shown in Tables 5 and 6, and an example of comparison plots of damage ratios is shown in Figure 2, in which the radiuses of plotted circles are proportional to weighting factors. In the figure, there are some points exceeding 100% because the total numbers of Data-B are used in order to calculate damage ratios of Data-K. Tables 5 and 6 indicate the regression lines pass through near the origin and those inclinations are around 0.6 in case of pairs of the corresponding rank. This means the damage ratios of Data-K are about 0.6 times of those of Data-B. In addition, it is also indicated that the coefficients of determination aggregated by blocks are smaller than those aggregated by neighborhood units in every combination of the damage ratio and have weaker correlativity. That is because average number of buildings in a block (11.1) is much smaller than that in a neighborhood unit (72.1). The histogram of relative frequency (frequency over total number of data) for the damage ratio of more-than-moderate damage is shown in Figure 3. In the calculation of relative frequency, the number of blocks or the number of neighborhood units is used for the total number of data. To sum up, the following are indicated in terms of the aggregation unit.

(1) In case that the aggregation unit is a block, which has smaller area, a damage ratio tends to be 0 or 1 because the number of buildings is small and the reliability of the damage ratio is low. In this case, the damage ratio has less correlation with the seismic intensity.

(2) In case that the aggregation unit is a neighborhood unit, which has larger area, the reliability of damage ratio is higher. Even in this case, if the seismic intensity ranges widely in an aggregation unit, the damage ratio has less correlation with the seismic intensity.

RELATIONS BETWEEN CELL SIZES AND BUILDING DAMAGE RATIOS

From the results of chapter 2, it becomes clear that there is an adequate range of aggregation unit area of building damage ratio. In this chapter, transitions of damage ratio distributions are examined with different cell sizes and the adequate range of cell size for the damage ratio is inquired.

In this study, Data-G is used because it has building polygons with damage ranking and it is not aggregated data. In practice, GIS data created by Ishii et al. (1996) are used. As shown in Figure 4, we selected two target areas in Higashinada Ward, Kobe City, which has mainly low-rise buildings with little damage by earthquake triggered fire in the 1995 Hyogo-ken Nanbu Earthquake. Area-A is middle area of Higashinada Ward (north-south 1.6km x east-west 4 km), which has little change of damage levels, and Area-B (north-south 3.2km x east-west 1.6 km) has large change of those. The studied cell sizes are 50m x 50m, 100m x 100m, 200m x 200m, 400m x 400m and 800m x 800m. The definition of the damage ratio in this study is as follows.

$$(\text{Damage Ratio}) = \frac{(\text{Complete Collapse or Heavy Damage}) + (\text{Light Damage})/2}{(\text{Total}) - (\text{Burned})} \tag{2}$$

This definition is not usually used, but generality is not lost with respect to the effect of cell sizes. We will use the term “the number of target buildings” to refer to the denominator of the definition fraction. The numbers of target buildings are shown in Figure 5 for each cell, in which the cells with no target buildings are not drawn. This figure makes it clear that large part of the cells that are smaller than 200m x 200m do not have more target buildings than 10. Regions that have few low-rise buildings locally are sites of schools, borough halls, parks, high-rise apartment buildings and so on. These characteristics of aggregation units considered being almost the same in other district than Higashinada Ward.

Relative frequencies of the damage ratios are shown in Figures 6 and 7. Cells that have no target buildings are excluded to calculate the damage ratios. These figures indicate that in case of 50m x 50m cells, relative frequencies of 0-10% and 90-100% are evidently larger than others because the numbers of target buildings are extremely few. Figure 5 reveals most of 50m x 50m cells do not have more target buildings than 10 and the cell is too small as an aggregation unit for the damage ratio.

By comparison of two damage ratio distributions in Figure 8, 800m x 800m cells cannot express local surge of the damage ratio. In other word, the damage ratio of an 800m x 800m is not reliable to assume the damage ratio to be uniform in a cell. From this point, cell size can be considered as resolution of damage distribution. In the 1995 Hyogo-ken Nanbu Earthquake, heavily damaged buildings are distributed in the narrow banded area. Cell size must be smaller than 800m x 800m to evaluate damage ratios considering this distribution of the damaged buildings.

Added to this, to consider the relation of damage ratio and seismic intensity, seismic intensity will not be uniform in an aggregation unit that has large area and the correlation of the damage ratio and the seismic intensity will be small. To sum up, the following are pointed out.

- When cell size is smaller than 50m x 50m, most of the number of target building in a cell will be equal to or less than 10 and damage ratio will be a discrete number like 0%, 50% or 100%. Therefore, the reliability of the damage ratio will be small. On the other hand, the larger the cell size becomes, the more the cells have the target buildings and the damage ratios distribute continuously.

- The damage ratio of a large cell is average value of those of small inner cells, and distribution of damage ratio can vary widely in a large cell like 800m x 800m, which cannot describe local surge of the damage ratio.

- The adequate cell size for the damage ratio of low-rise building ranges from 100m x 100m to 400m x 400m from a viewpoint of reliability of the damage ratio and resolution of damage distribution, and the adequate area of an aggregation unit ranges from 10,000 m^2 to 200,000 m^2 approximately.

In case of middle- and high-rise buildings, because area of a site is larger than that of a low-rise building, the number of target buildings in a cell would be smaller than that in case of low-rise buildings. Thus, the lower limit of cell size is larger than that in case of low-rise buildings. On the other hand, the upper limit would be the same as in case of low-rise buildings because the distribution of seismic intensity is considered to be the same.

EXAMINATION OF REGIONAL CELL SIZES

The distributions of areas and target buildings for two kinds of aggregation units, neighborhood units and blocks, are shown in Tables 7 and 8. The upper limit of each area class is based on the cell sizes of the previous chapter. The damage ratio aggregated by blocks has low reliability because 65% of blocks have smaller area than 2,500m^2, which is corresponding to a 50m x 50m cell, and about 60% of blocks have less target buildings than 10. On the other hand, 99% of neighborhood units have smaller area than 160,000m^2. The previous chapter revealed that the local surge of the damage ratio could be detected by cell size that is smaller than about 200,000m^2. Therefore, neighborhood units can describe local change of the damage ratio distribution. With regard to reliability of the damage ratio, which is from the number of target buildings, 63% of the neighborhood units has more than 32 target buildings, 22% of them has less than 17 and 15% of them has less than 8 and most of them have little problem. But 10-20% of them has still few target buildings and should be considered in some way, for example, excluding them from examination, using target buildings as weight factor shown in this study and so on.

CONCLUSIONS

Estimation of the distribution of damaged buildings generated by a damaging earthquake is one of the most fundamental tasks in selecting the optimal measures to mitigate potential earthquake disasters. Fragility functions, which estimate ratios of damaged buildings based on the seismic intensity, are very convenient and effective for this purpose. The characteristics of the damage ratio data, which is necessary to evaluate fragility functions, are examined with databases concerning buildings damaged by the 1995 Hyogo-ken Nanbu Earthquake and the following results are obtained.

(1) Two kinds of databases, that of Civil Engineering Studies, Department of Architecture and Civil Engineering, Faculty of Engineering, Kobe University (Data-K) and that of the Building Research Institute, Ministry of Construction (Data-B), are compared by regression analyses with respect to two aggregation units, neighbourhood units and blocks. The damage ratios of Data-K are about 60% of those of Data-B.

(2) From the comparison of damage ratio distributions for neighborhood units and blocks, blocks have bad correlation to seismic intensity because the number of target buildings in a unit would be extremely small and their damage ratio would often be a discrete number like 0% or 100%.

(3) For cities with the same density as Higashinada Ward, an aggregation unit for damage ratio of low-rise building should be larger than about 10,000km^2 from a viewpoint of reliability of the damage ratios, and smaller than about 200,000km^2 from a viewpoint of resolution of damage distribution.

(4) In Kobe, the damage ratios of low-rise buildings by block units have low reliability but those by neighborhood units are reliable comparatively.

ACKNOWLEDGEMENTS

This study is based on the precious damage data of Civil Engineering Studies, Department of Architecture and Civil Engineering, Faculty of Engineering, Kobe University, the Building Research Institute, Ministry of Construction and the Geographical Survey Institute, Ministry of Construction. I would like to thank those creators of the data. The GIS data used in the chapter 3 are created by Mr. Akira Ishii and Dr. Shigeru Nagata and some data are collected with aid and comfort of Mr. Jun Tagami in Kajima Corporation. I would like to thank them, too.

Maps in this study are created based on CD-ROM data by Building Research Institute of Japan, which is copy of the Digital Map 10000 (syntactic) issued by Geographical Survey Institute of Japan with its approval (the endorsement number: Hei-8-Sou-Fuku, No. 26).

REFFERENCES

Aoki, Y. (1998), "Note on Modifiable Areal Unit Problem", *Comprehensive Urban Studies*, 65, pp17-23.

Architectural Institute of Japan and City Planning Institute of Japan (1995), *Report of Emergency Damage Survey of the 1995 Hyogoken-Nanbu Earthquake.*

Ashiya City Government (1997), *the Hanshin-Awaji Earthquake Disaster: Report of Ashiya City '95-'96*.

Building Research Institute of Japan (1996), *Final Report of Damage Survey of the 1995 Hyogoken-Nanbu Earthquake.*

Field Investigation Team on Great Hanshin Earthquake, Department of Civil Engineering, Faculty of Engineering, Kobe University (1995), *2nd Report on Great Hanshin Earthquake*.

Geographical Survey Institute of Japan (1995), *Report of Emergency Damage Survey of the 1995 Hyogoken-Nanbu Earthquake by Aerial Photographs (2nd Edition).*

Hasegawa, K., Midorikawa, S. and Matsuoka, M. (1998), "Seismic Risk Mapping of Wooden House In Large Area Using the Grid-Square Statistics: Part 2 Vulnerability functions of wooden houses with different construction age and example of seismic risk mapping", *Journal of Structural and Construction Engineering AIJ*, 505, pp53-59.

Ishii, A., Moroi, T., Nagata, S., Ishida, H. and Ohbo, N. (1996), "Seismic Damage Analysis Using Geographic Information System", *Proceedings of Academic Conference on Hanshin-Awaji Earthquake Disaster JSCE*, pp753-760.

Kashima, T., Takada, S., Mizukoshi, K., Ishida, H., Tagami, J. and Hayasaka, H. (1996), "Macroscopic Study on Building Damage at the 1995 Hyogo-ken Nanbu Earthquake: (Part 2) Evaluation of Fragility Curve of Buildings", *Summaries of Technical Papers of Annual Meeting AIJ*, pp3-4.

Kinki Chapter, Architectural Institute of Japan (1995), *the 1995 Hyogoken-Nanbu Earthquake: the Damage of Wooden buildings*.

Miyakoshi, J., Hayashi, Y., Watanabe, K. and Tamura, K. (1997), "Seismic Performance Evaluation of Buildings from Building Damage of the 1995 Hyogo-Ken-Nanbu Earthquake", *Proceedings of Structural Engineering AIJ*, Vol.43B, pp269-276.

Murao, O. and Yamazaki, F. (1998), "A Comparison of Building Damage Evaluation due to the 1995 Hyogoken-Nanbu Earthquake: The Case of Ashiya City", *Summaries of Technical Papers of Annual Meeting AIJ*, pp789-790.

Shibata, A. and Akamatsu, M. (1988), "Prediction of Earthquake Damage to Wooden Building Groups in Urban Areas", *The Architectural Reports of Tohoku University*, 27, pp91-101.

Tagashira, N. (1990), "Spatial Aggregation Problems: The Effect of Spatial Data Aggregation to the Model-Fitting", *Papers on City Planning CPIJ*, 25, pp361-366.

Tong, H., Yamazaki, F., Sasaki, H. and Matsumoto, S. (1994), "A Relationship between Seismic Ground Motion Severity and House Damage Ratio", *Proceedings of the 9th Japan Earthquake Engineering Symposium*, pp.2299-2304.

Table 1: Outlines of the building damage databases

		Data-K	Data-B	Data-G
Building Damage Survey	Inquirer	Field Investigation Team on Great Hanshin Earthquake, Department of Civil Engineering, Faculty of Engineering, Kobe University	Architectural Institute of Japan, City Planning Institute of Japan and Planning Division, Urban and Housing Department, Hyogo Prefecture	the same parties as left and Geographical Survey Institute of Japan
	Period	(1^{st}) Jul. 20 – Jul. 28,1995 (2^{nd}) Feb. 1– Feb. 11,1995 (3^{rd}) Mar. 7 – Mar. 11,1995	the Special Committee for Re-construction City Planning of the Earthquake Disaster: (1^{st}) Feb. 1 – Feb. 9, 1995 (2^{nd}) Feb. 10 – Mar. 13, 1995 City Planning Office, Hyogo Prefecture : March, 1995 March, 1995	the same as left; flight for aerial photo: Jan. 17,18,20 and Feb. 11, 1995
	Purpose	accurate hold of state of stricken area; drawing stricken area map	to recording perspective of the disaster by ranking building damage by externals	the same as left; accurate hold and recording of the diversified disaster
	Procedure	using residential map; judgement by externals; taking photos	using residential map; judgement by externals; putting ranking marks in the map	the same as left; visual judgement of aerial photos (other area than left)
	Area	area indicated in the report of KU (1995) of Kobe, Ashiya, Nishino-miya, Amagasaki, Takarazuka, Itami, Kawa-nishi, Awaji, Hokutan, Ichinomiya, Higashiura and Tsuna	Kobe, Ashiya, Nishinomiya, Ama-gasaki, Takarazuka, Itami, Kawa-nishi and Awaji Island (parts of Awaji, Hokutan, Higashiura)	the same as left and parts of Awaji Island, Toyonaka, Suita, part of Osaka and so on.
Database	Creator	the same as the inquirer	Building Research Institute of Japan	Geographical Survey Institute of Japan
	Data Type	GIS data	GIS data	map
	Data Unit	building	block neighborhood unit	more than $4mm^2$ area in a 1/10000 map
	GIS Base Map	1:2500 city planning map, aerial photos	Digital Map 10000, Digital Mapping data (Kobe), 1:2500 city planning map (other cities)	1:10000 topographic map revised in 1995
	Object Area	the same as the above survey area	the same as the above survey area except Nishi Ward and Kita Ward, Kobe and Awaji Island	the same as the above survey area
	Data Inventory	story; building type: firm (more than three story, middle or high-rise building) / normal (one or two story, low-rise building) / shanty (connecting corridor, bicycle shed and so on)	usage: Independent residence / collective housing / business facility / industrial or distributive facility / other / unknown building type: firm / non-firm / shanty / unknown	building type: high-rise (more than three story) / low-rise (one or two story)

Table 2: Criteria of damage ranking

Data-K		Data-B		Data-G	
Complete Collapse	tilted; completely collapsed; impossible to repair	Rank C (Complete Collapse or Heavy Damage)	not reusable; little expect of inhabitability	Complete Collapse or Heavy Damage	(combining rank B and C of Data-B)
Half Collapse	large cracks and deformation; reusable with repairs; often without residents	Rank B (Moderate Damage)	reusable with considerable repairs		
Partial Damage	cracks; usable without repairs	Rank A (Light Damage)	light damage and usable; reusable with light repairs	Light Damage	(rank A of Data-B)
No Damage	(no explanation)	No Damage (by externals)	no damage by externals	(no legend)	

Table 3: Numbers of buildings for each aggregation unit (based on Data-B)

	Neighborhood Unit	Block
Number of Aggregation Units	1,321	9,365
Low-rise buildings	95,223	104,882
Middle or high-rise building	20,319	21,756
Total (including shanty)	122,164	133,545

Table 4: Definitions of damage ratios

	Data-K	Data-B
Complete Collapse	$\dfrac{(\text{Complete Collapse})}{(\text{Total in data - B}) - (\text{Burned})}$	$\dfrac{(\text{Rank C})}{(\text{Total}) - (\text{Burned}) - (\text{Unknown})}$
More than Moderate Damage	$\dfrac{(\text{Complete Collapse}) + (\text{Moderate Damage})}{(\text{Total in data - B}) - (\text{Burned})}$	$\dfrac{(\text{Rank C}) + (\text{Rank B})}{(\text{Total}) - (\text{Burned}) - (\text{Unknown})}$
More than Light Damage	$\dfrac{(\text{Complete Collapse}) + (\text{Moderate Damage}) + (\text{Light Damage})}{(\text{Total in data - B}) - (\text{Burned})}$	$\dfrac{(\text{Rank C}) + (\text{Rank B}) + (\text{Rank A})}{(\text{Total}) - (\text{Burned}) - (\text{Unknown})}$

Table 5: Results of regression analyses on damage ratios (neighborhood unit)

		Y (Data-K)		
		Complete Collapse	More than Moderate Damage	More than Light Damage
X (Data-B)	Complete Collapse	Y = -0.009 + 0.586 X R^2 = 0.576	Y = 0.077 + 0.749 X R^2 = 0.585	Y = 0.378 + 0.513 X R^2 = 0.254
	More than Moderate	Y = -0.047 + 0.433 X R^2 = 0.407	Y = -0.013 + 0.633 X R^2 = 0.538	Y = 0.282 + 0.498 X R^2 = 0.308
	More than Light	Y = -0.116 + 0.385 X R^2 = 0.203	Y = -0.161 +0.624X R^2 = 0.329	Y = 0.049 + 0.641 X R^2 = 0.322

Table 6: Results of regression analyses on damage ratios (block)

		Y (Data-K)		
		Complete Collapse	More than Moderate Damage	More than Light Damage
X (Data-B)	Complete Collapse	Y = 0.004 + 0.539 X R^2 = 0.452	Y = 0.087 + 0.687 X R^2 = 0.466	Y = 0.369 + 0.482 X R^2 = 0.200
	More than Moderate	Y = -0.029 + 0.395 X R^2 = 0.313	Y = 0.003 + 0.587 X R^2 = 0.439	Y = 0.278 + 0.474 X R^2 = 0.250
	More than Light	Y = -0.071 + 0.320 X R^2 = 0.141	Y = -0.091 + 0.516 X R^2 = 0.234	Y = 0.094 + 0.562 X R^2 = 0.242

Table 7: Areas of each aggregation unit

Area ×100 m^2	Square Root of Upper limit* m	Neighborhood Unit		Block	
		Frequency	Relative Freq.	Frequency	Relative Freq.
0 - 25	50	2	0.00	6080	0.65
25 - 100	100	177	0.13	2917	0.31
100 - 400	200	917	0.69	335	0.04
400 - 1600	400	208	0.16	28	0.00
1600 - 6400	800	16	0.01	5	0.00
6400 - 25600	1600	1	0.00	0	0.00
25600- 102400	3200	0	0.00	0	0.00
Total		1321	1.00	9365	1.00

* corresponding to a cell size

Table 8: Total number of buildings

Buildings	Neighborhood Unit		Block	
	Frequency	Relative Freq.	Frequency	Relative Freq.
0	68	0.05	1994	0.21
1	30	0.02	443	0.05
2	19	0.01	414	0.04
3, 4	27	0.02	830	0.09
5 - 8	54	0.04	1643	0.18
9 - 16	91	0.07	2281	0.24
17 - 32	204	0.15	1475	0.16
33 -	828	0.63	285	0.03
Total	1321	1.00	9365	1.00

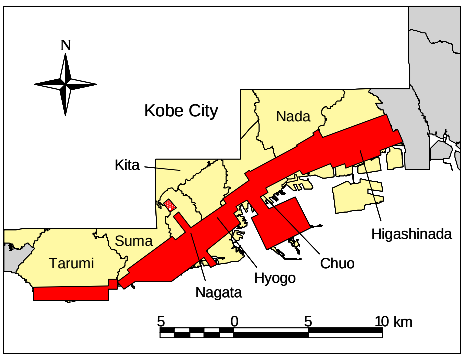

Figure 1: Target area of damage ratio comparison

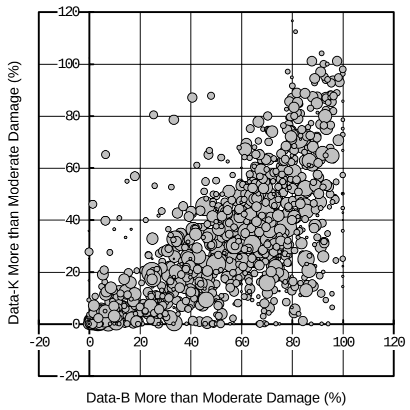

Figure 2: A damage ratio comparison (neighborhood unit)

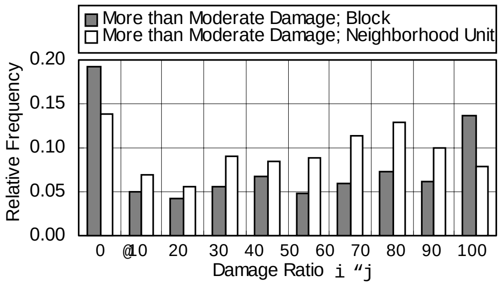

Figure 3: Relative frequency of damage ratio of more than moderate damage

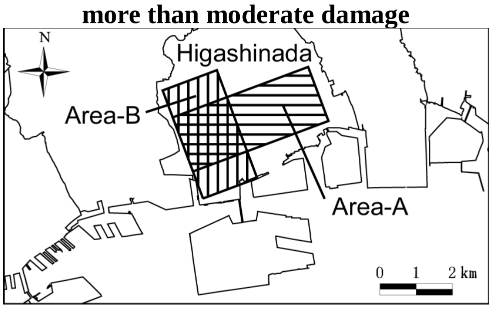

Figure 4: Target area for cell division analysis

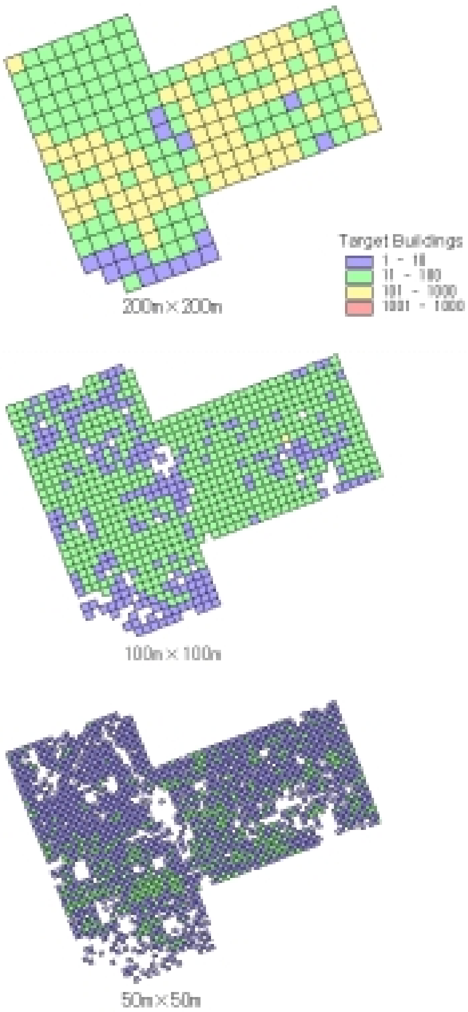

Figure 5: Distributions of target buildings

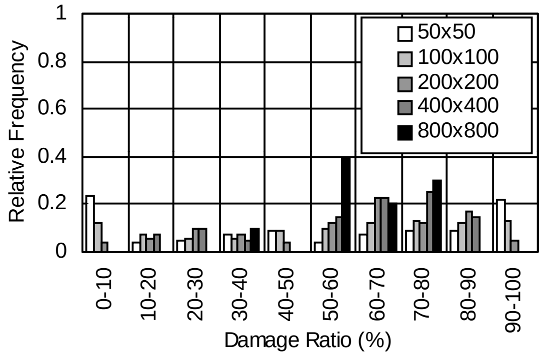

Figure 6: Relative frequency of damage ratio in Area-A

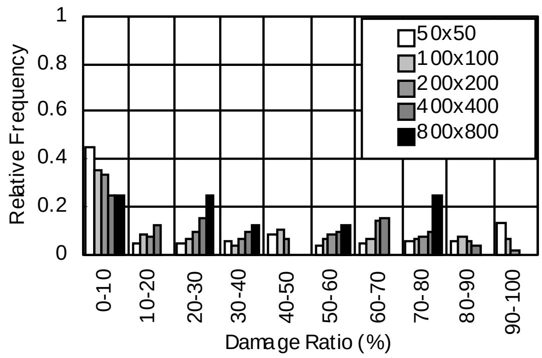

Figure 7: Relative frequency of damage ratio in Area-B

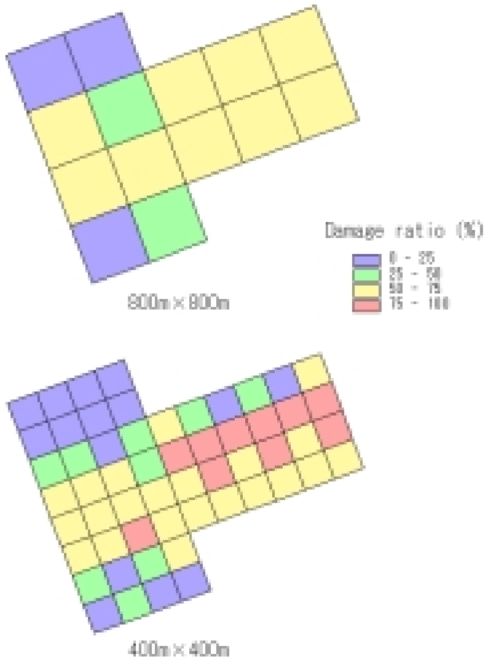

Figure 8: Distributions of damage ratios