USE OF MICROSCOPIC GIS DATA FOR EARTHQUAKE SCENARIO OF URBAN RESIDENTIAL AREAS

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ABSTRACT

Earthquake damage assessment that considers characteristics of local areas is proposed. Since existing damage assessments conducted by jurisdictions in Japan seem like mere summary of numbers, it may be difficult for local residents to visualize an earthquake disaster around them. Hence, in this study, a damage assessment is conducted using geographic information system (GIS) for three typical residential areas in Tokyo with a scale that can distinguish each house. For this purpose, as much information of the areas as possible was collected, e.g., national census data for residents, characteristics of buildings, land use, roads and public facilities, soil conditions. A questionnaire survey on disaster preparedness is also conducted among the residents. A scenario earthquake which occurs just beneath Tokyo with a magnitude of 7.0 is considered. Structural damage is estimated for each house and building within the areas. Secondary disasters, e.g., associated fires, are also estimated. The results of the estimation are displayed on a workstation in visual form, which clearly demonstrates the difference among the three areas. An earthquake scenario is then developed by synthesizing all the acquired data.

1. INTRODUCTION

In recent years, scores of earthquake damage estimations for scenario earthquakes have been conducted by local and national governments in Japan. These studies aim to identify the extent of earthquake damage and use the results for formulating disaster countermeasures. For this purpose, the area for a survey is divided into small square meshes with a side of 500 m or 1 km. Then, the earthquake ground motion and various kinds of damage are predicted for each mesh. The results of damage estimation are then synthesized and the statistics are shown in tabulated form.

Although the results of such studies may be useful for jurisdictions, it is difficult for local residents to visualize a disaster since the predictions are shown in a very macroscopic manner. "What are going to occur in his/her house and neighborhood?" is the major concern of ordinary people. From this point of view, this paper proposes an earthquake damage estimation methodology with enhanced use of characteristics of local areas. The geographic information system (GIS) is fully utilized to characterize, analyze and visualize the studied areas. Three residential districts in Tokyo Metropolis are selected as test sites where the microscopic earthquake damage estimation is conducted.

After the Great Hanshin Earthquake on January 17, 1995, many projects to make digital maps of the affected areas have started. Such GIS data will be used to verify the methods proposed in this paper.

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2. CHARACTERISTICS OF THE THREE RESIDENTIAL AREAS IN TOKYO

2.1 Selection of Areas to Study

About 8 million people live in the 23 wards (or "ku"s) of Tokyo Metropolis. Seismic vulnerability of each area of Tokyo is not uniform since considerable differences in ground conditions, buildings and residents exist. To demonstrate the difference in seismic vulnerability within a big city, three residential areas in Tokyo are selected. Figure 1 shows the locations of the three areas: Azabu in Minato-ku, Tsurumaki in Setagaya-ku, and Sumida in Sumida-ku. Azabu represents a high-class residential area located in the heart of Tokyo. Tsurumaki is a typical new residential area located in western Tokyo (hillyland). Sumida is a typical old residential area located in eastern Tokyo (lowland).

Table 1 summarizes the basic characteristics of the three areas, extracted from the national census. Tsurumaki has the largest area and population. Sumida has the smallest area but has a population larger than Azabu. Thus, the population density is largest in Sumida and smallest in Azabu. In Tsurumaki and Sumida, the daytime population is smaller than the (night) population, which is usual for residential areas. However, in Azabu, the daytime population is larger than the night population, indicating existence of business and educational facilities.

2.2 Topography and Geology

Figure 2 shows the topography of the three areas, extracted from the geological map of Tokyo and plotted digitally by a GIS software ARC/INFO (ESRI, 1989). Azabu is located at the eastern edge of the Musashino tableland. The central part of Azabu is a hill of an altitude about 30 m, which is surrounded by an old riverbed of an altitude about 5-10 m and sloping ground. Hence, a rather strong contrast is seen in the topography of Azabu.

Tsurumaki is located on a tableland of an altitude larger than 30 m. An old riverbed lies in its central part from the west to the east. Its topography is similar as that of Azabu but with smaller undulation.

Sumida has a quite different topography compared with the two other areas. It is surrounded by Arakawa and Sumida rivers and is located on delta and natural riverbank. The altitude of Sumida is mostly less than 0 m, which means the ground level is lower than the water table of the rivers.

Boring data are collected for the three areas and predominant periods of ground are estimated at the borehole locations. Then, spatial distribution of predominant period is estimated based on the Kriging technique. The estimated predominant period of ground is mostly 0.15-0.6 s in Azabu and Tsurumaki while mostly 0.9-1.2 s in Sumida. The authors conducted microtremor observations at several locations and the results were close to the estimated predominant periods in most cases.

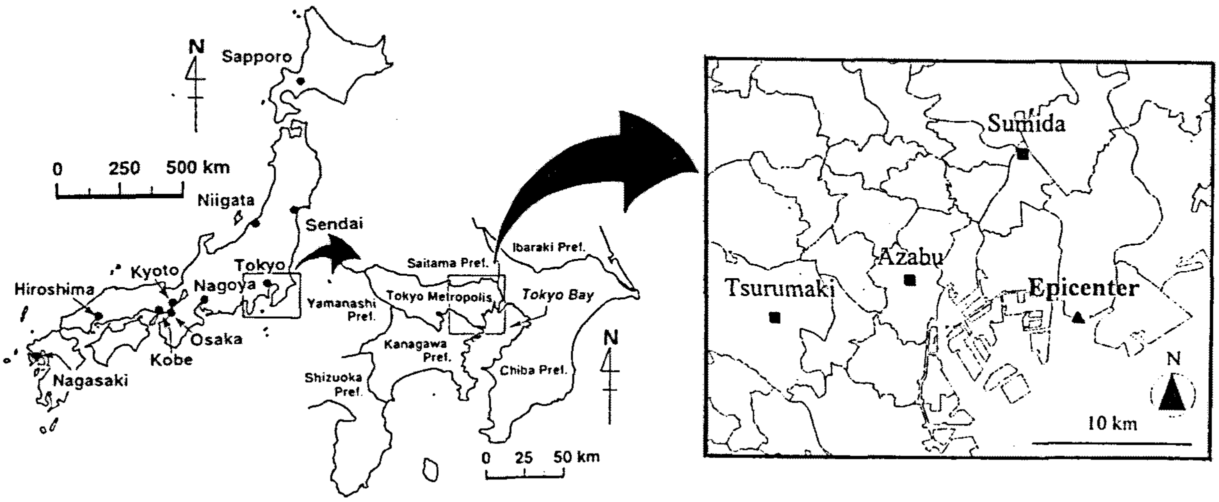
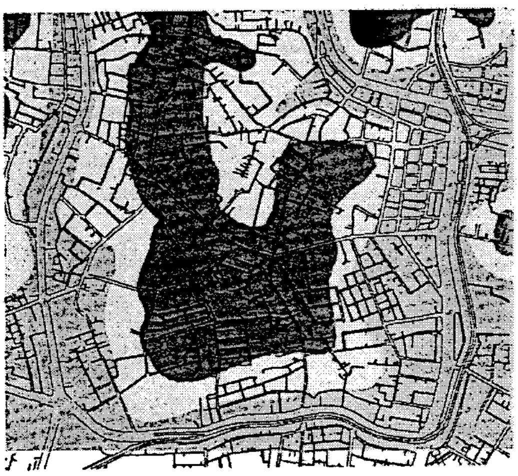


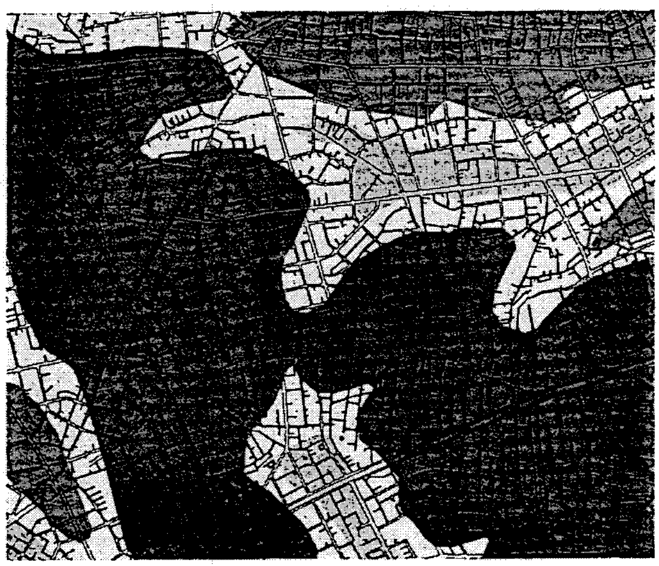
Figure 1 Location of the three residential areas in Tokyo for this study

Table 1 Area and population of the three areas in Tokyo for this study

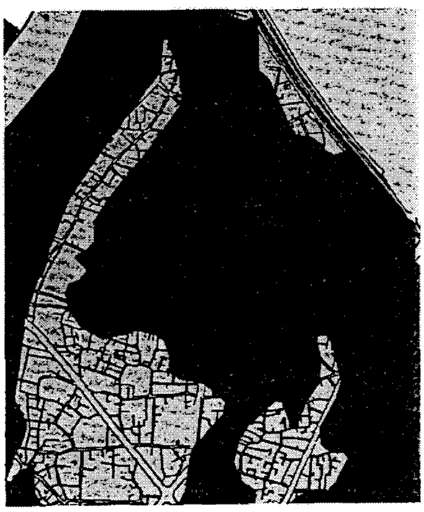
	Azabu	Tsurumaki	Sumida
area [km^2] : A	1.364	1.886	1.173
night population : B	18559	32128	21066
daytime population : C	22324	27434	18367
population density: B/A [$1/km^2$]	13606	17035	17959
daytime vs. night population ratio: C/B	1.203	0.854	0.872



(a) Azabu



(b) Tsurumaki



(c) Sumida

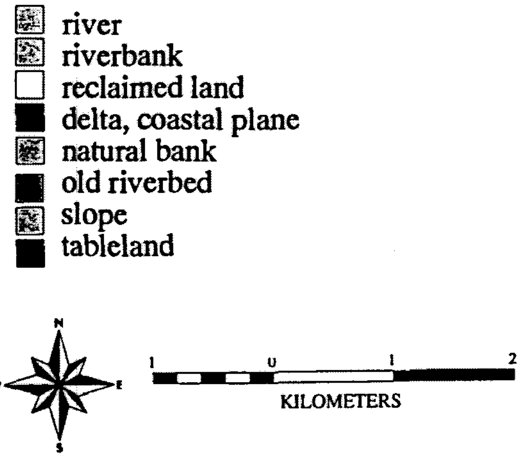


Figure 2 Topography of the three residential areas in Tokyo

2.3 Characteristics of Buildings

Table 2 summarizes the total number of buildings in these areas. Although Sumida has the smallest area, it has the largest number of buildings, which indicates densely located small houses. Azabu has the largest average land area for one building (total area divided by number of buildings) and Tsurumaki, the second largest. The average land area for one building in these areas is about twice that in Sumida, indicating buildings are large and/or open space is large in Azabu and Tsurumaki.

The city planning division of the Tokyo Metropolitan Government made maps of each ward in which the structural type, the number of stories, and the use of each building are shown. Digital maps for the three studied areas were made by the authors based on such paper maps.

Figure 3 is an example of the digital map on a workstation using ARC/INFO, in which the structural type of each building in four categories is shown. The structural types of buildings are also summarized in Table 2. The ratio of fire-resistant buildings, e.g., reinforced concrete and steel frame buildings, is highest in Azabu (33.8%) and lowest in Sumida (2.1%). The ratio of wooden houses (fire-retarded wooden and pure wooden) is very high in Tsurumaki (82.3%) and Sumida (84.3%), which is usual in residential areas of Japan.

Table 3 shows the story classification of buildings in the three areas. The ratio of one story buildings are almost the same for the three areas (about 11%). Two story buildings have the highest ratios in all the areas, especially high in Tsurumaki (79.4%) and Sumida (81.5%), which almost correspond to the ratio of wooden houses. The ratio of buildings over two story is highest in Azabu (29.3%) among the three areas.

The buildings in the three areas are mostly residential use. The ratio of commercial, office, school and industrial buildings is highest in Azabu (20% in total). In Sumida, the buildings for both residential and commercial uses comprise 22% of the total, and those for both residential and manufacturing uses comprise 11%, indicating a high percentage of domestic industry.

2.4 Characteristics of Residents

In constructing microscopic earthquake damage scenario, it is important to grasp the characteristics of residents. The national census data are fully employed in this purpose. Table 4 shows the ratios of age groups of residents in the three areas. The ratio of young generation (19-29 years old) is the highest in Tsurumaki because there are many apartments for students and young businessmen. The average age of residents in Azabu is higher than that of Tsurumaki since the land price and rent in Azabu is very high, thus not affordable to the young. The ratios of middle age (45-64) and senior citizen (65 and over) are highest in Sumida since it is the oldest residential area among the three. Hence, in case of disasters like earthquake or fire, Sumida has many vulnerable people. But, as a community, ties among residents are stronger in Sumida than in the other two. These two facts may affect the response of residents in case of disaster.

Table 5 shows the ownership of residence in the three areas. Owner-occupation rate is the highest in Sumida (59.0%) and much lower in Azabu (36.8%) and Tsurumaki (34.8%). The ratio of private rental houses/apartments is highest in Tsurumaki, corresponding to the dominance of young generation.

Table 2 Number and structural type of buildings

	Azabu	Tsurumaki	Sumida
number of buildings	2884	4640	5103
fire-resistant (%)	33.8	8.9	2.1
semi fire-resistant (%)	9.3	8.8	13.6
fire-retarded wooden (%)	39.3	56.9	64.6
wooden (%)	17.6	25.4	19.7

Table 3 Story classification of buildings (%)

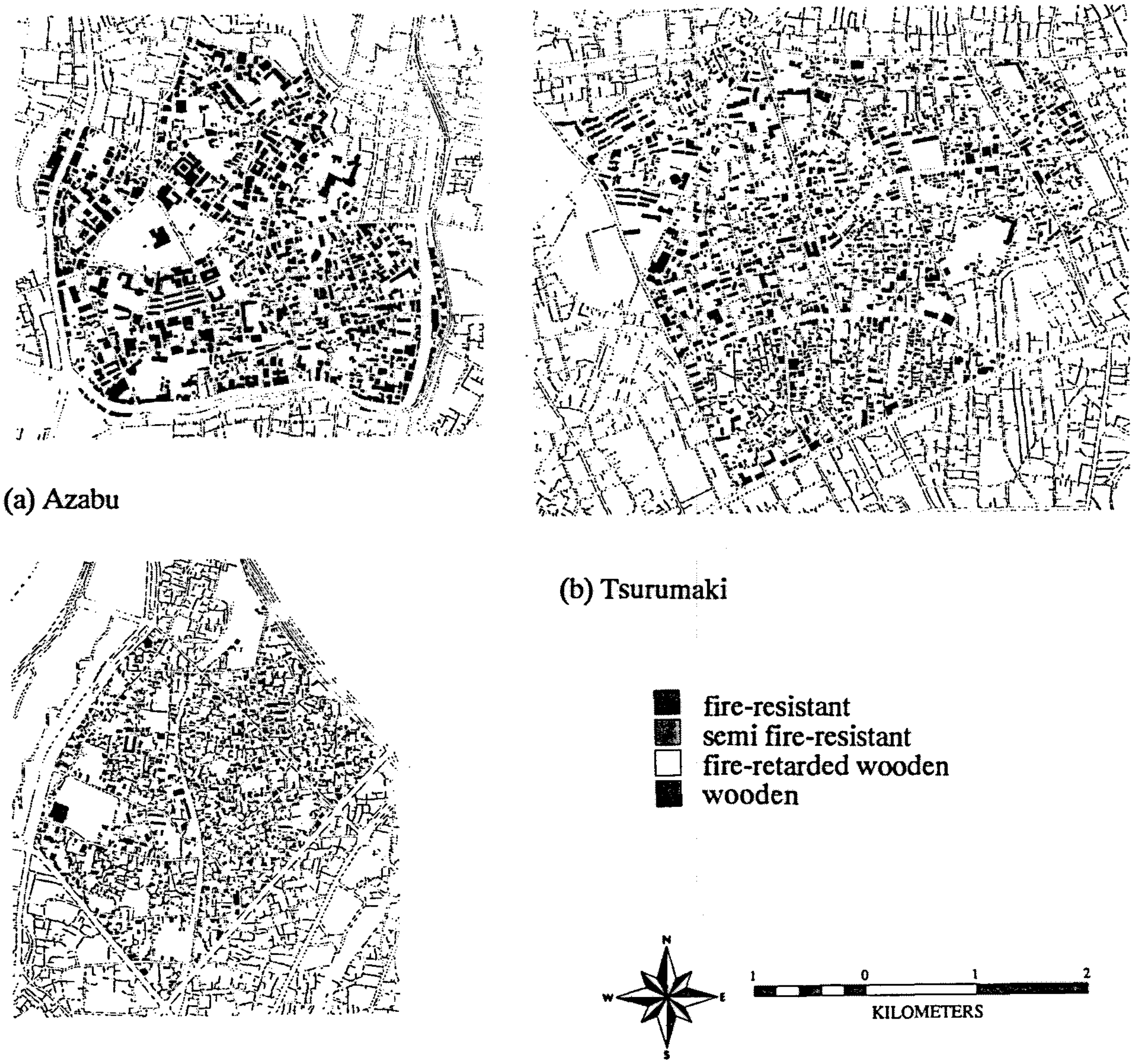
	Azabu	Tsurumaki	Sumida
1 story	11.20	11.19	11.39
2 story	59.54	79.44	81.48
3-5 story	24.69	8.86	7.05
6-10 story	4.19	0.47	0.08
over 10 story	0.38	0.04	0.00

Table 4 Composition of residents by age

age group	Azabu	Tsurumaki	Sumida
18 and less (%)	20.05	20.11	18.34
19 - 29 (%)	16.98	23.92	17.08
30 - 44 (%)	24.91	23.66	19.44
45 - 64 (%)	26.03	22.47	29.94
65 and over (%)	12.03	9.84	15.20

Table 5 Ownership of residence for family (%)

	Azabu	Tsurumaki	Sumida
owner-occupied	36.82	34.79	58.99
public rental	2.46	4.21	3.14
private rental	39.08	46.12	32.33
company apartment	15.96	7.76	2.11
others	5.68	7.12	3.43



(a) Azabu

(b) Tsurumaki

(c) Sumida

Figure 3 Structural type of buildings in the three residential areas

3. DAMAGE ESTIMATION FOR SCENARIO EARTHQUAKE

3.1 Scenario Earthquake and Predicted Ground Motion

To assess seismic vulnerability of the three residential areas, a scenario earthquake is considered. The earthquake is modeled after the 1855 Ansei-Edo Earthquake, which occurred just beneath Tokyo lowland (Figure 1). The magnitude is estimated as 7.0 and the focal depth as 20 km. Although the epicentral distances to the three areas are somewhat different, the distance used to evaluate earthquake ground motion is assumed as 10 km for all the three sites.

Using the attenuation equation by Annaka and Nozawa (1988), the acceleration response spectrum of 5% damping and the peak ground acceleration (PGA) are evaluated. Site amplification effects are considered using a spectrum ratio by Okumura et al. (1994), which models surface layers by an equivalent single layer on half space. The impedance ratio between the base and surface layers is a dominant factor to determine the soil amplification.

Figure 4 shows the acceleration response spectra of the base layer and the ground surface of three soil models. The predominant periods of surface layers can be seen in the response spectra. The distribution of estimated PGA for the three areas is shown in Figure 5. In the figure, the PGA is estimated higher as the predominant period becomes longer. The distribution of PGA is quite uniform in Sumida since the soil condition has small variation. On the contrary, the PGA shows notable spatial variation in Azabu and Tsurumaki. This kind of variation in earthquake ground motion cannot be taken into account in mesh-type earthquake damage estimation by jurisdictions.

3.2 Structural Damage to Buildings

For the earthquake ground motion estimated above, structural damage is evaluated per building. Conventional simple approaches are employed since the data we have for each building are limited: structural type, number of stories, use and area. Taxation lists are needed if we want to get more detailed information, e.g., year of construction and detailed structural type.

For wooden houses, the predominant period was estimated based on the number of stories (one or two) and structural type (pure wooden or fire-retarded wooden). Using a simple elasto-plastic response method (Kanagawa Pref., 1985), the damage to all the wooden houses in the three areas was evaluated by the ductility factor μ as tabulated in Table 6 and plotted in Figure 6. In this estimation, the effect of liquefaction was considered in Sumida, where most parts have moderate liquefaction potential and a small part has high liquefaction potential.

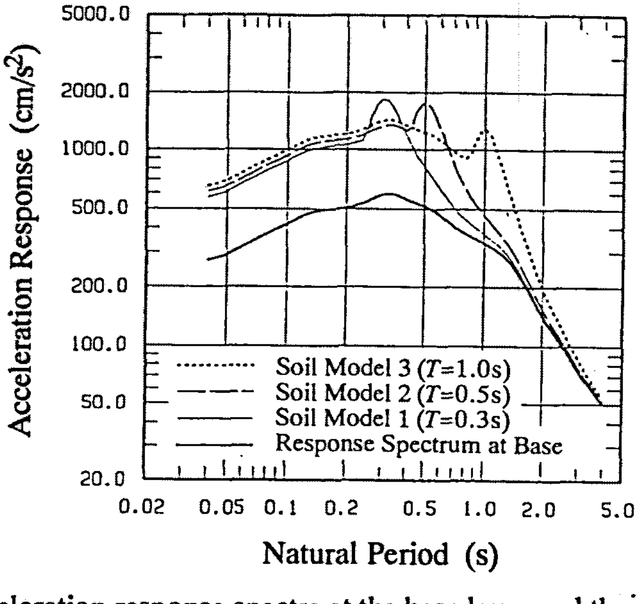
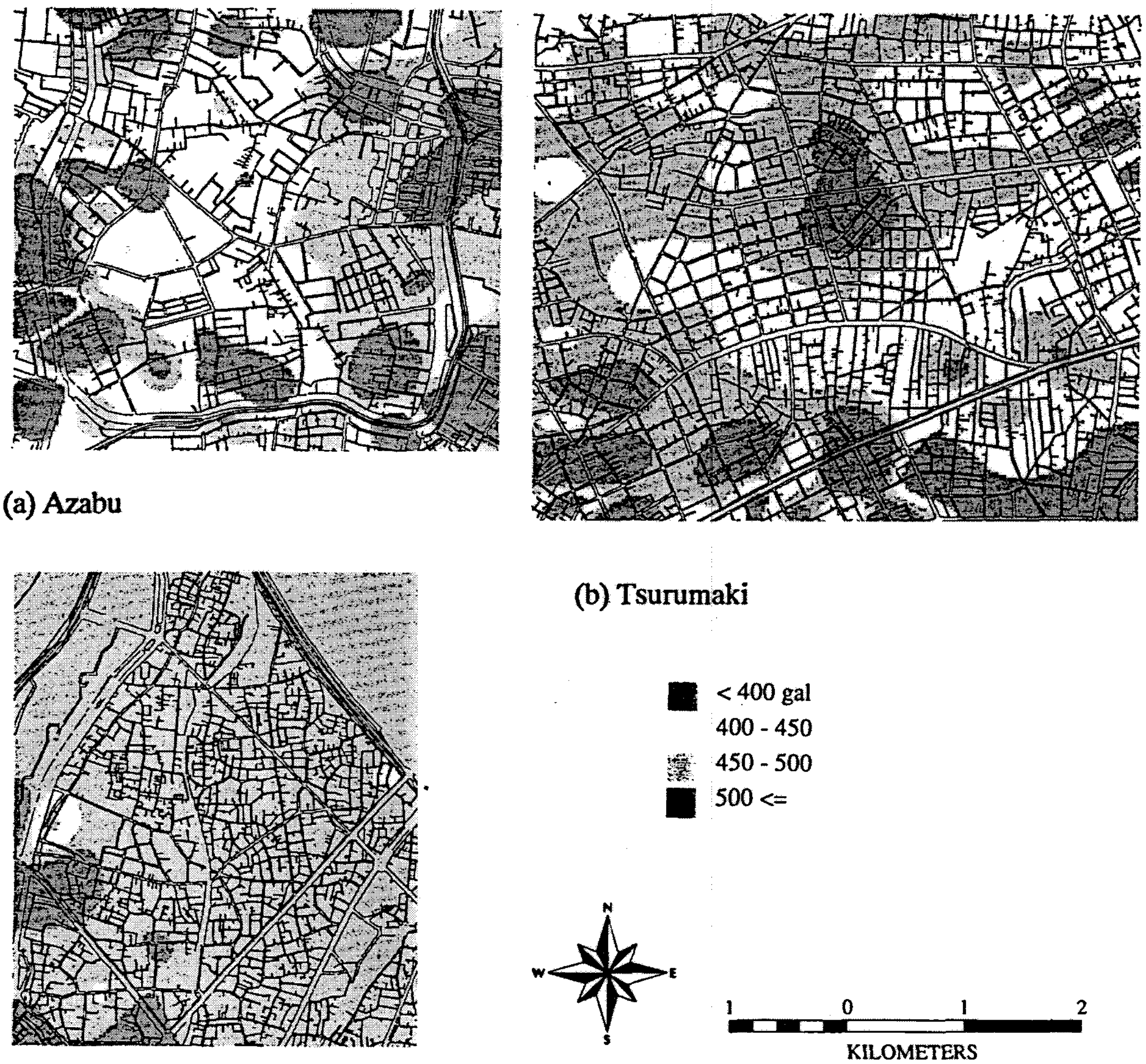


Figure 4 Acceleration response spectra at the base layer and the surface of 3 soil models



(c) Sumida

Figure 5 Peak ground acceleration (PGA) of the three areas for the scenario earthquake

Comparing the three areas, Sumida has the largest severe damage ($\mu>6$) ratio mainly due to liquefaction. In each area, the distribution of ductility factor corresponds to the distribution of the predominant period of ground. Structural damage to wooden houses occurs extensively, which corresponds to the structural damage in the Great Hanshin Earthquake (AIJ,1995). However, except for the Great Hanshin Earthquake, it is not the case in recent earthquakes in Japan. More careful examination may be necessary for strength of wooden houses in Japan, especially, from the view point of regional difference.

A similar damage estimation was conducted for all the fire-resistant and semi fire-resistant buildings using the method by Okada and Nakano (1988). Since we have no data of construction age, seismic resistance of these buildings were estimated as that of buildings constructed after 1973, whose seismic resistance was studied by Okada and Nakano (1988). The results of the damage estimation are summarized in Table 7. No building falls in the category of severe damage and a small percentage of buildings were estimated to be of moderate damage. One of the possible reasons for this little damage is the overestimation of seismic

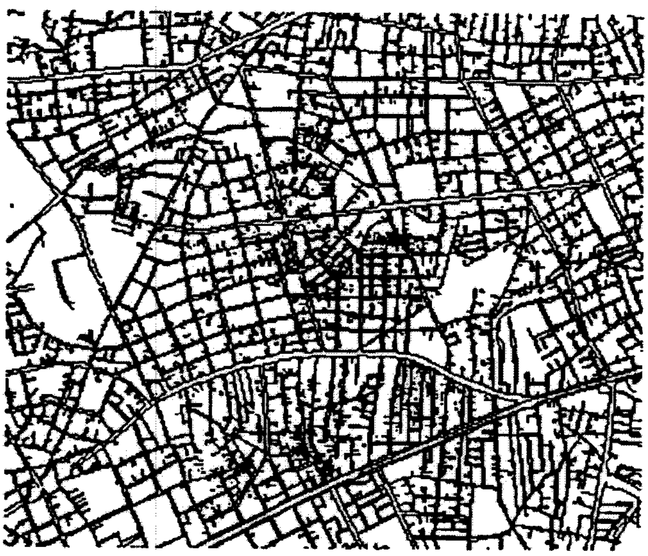
Table 6 Estimated damage of wooden and fire-retarded wooden houses (%)

Damage category	Azabu	Tsurumaki	Sumida
minor or no damage $\mu < 3$	30.7	7.5	1.5
moderate damage $3 \leq \mu < 6$	57.5	72.9	72.6
severe damage $\mu \leq 6$	11.8	19.6	25.9

Table 7 Estimated damage of fire-resistant and semi fire-resistant buildings (%)

Damage category	Azabu	Tsurumaki	Sumida
minor or no damage $Is0/Is < 2$	94.0	90.3	100.0
moderate damage $2 \leq Is0/Is < 4$	6.0	9.7	0.0
severe damage $Is0/Is \leq 4$	0.0	0.0	0.0

(a) Azabu



(b) Tsurumaki

(c) Sumida

minor or no damage ($\mu < 3$)

moderate damage ($3 \leq \mu < 6$)

severe damage ($\mu \leq 6$)

Figure 6 Damage of wooden and fire-retarded wooden houses by the scenario earthquake resistance of old buildings constructed before 1973. Since many old reinforced buildings collapsed in the Great Hanshin Earthquake, it is highly important to know construction ages of buildings, which correspond to their adopted design codes.

3.3 Fire Following Earthquakes

Fires after earthquakes are the most damaging but uncertain factor in an earthquake damage scenario. In our microscopic damage estimation, the probability of fire breakout for each building is calculated based on the method by the Tokyo Fire Department (1987), which uses the floor response spectrum, floor area and use of each building.

The total number of fire breakout was 0.3 in Azabu, 1.2 in Tsurumaki and 0.5 in Sumida for the scenario earthquake. Tsurumaki has the largest number because there are many wooden apartment buildings. Computer simulations of fire spread were then performed assuming one fire breakout for each area. Figure 7 shows the results of simulation for Sumida. Since the density of wooden houses is very high, the speed of fire spread is fastest in Sumida.

In fire spread simulation, we still have many issues to be considered, e.g., effects of fire fighting activities, trees, parking cars, and fire spread speed for torn down houses.

4. QUESTIONNAIRE SURVEY AMONG RESIDENTS

A questionnaire survey was conducted among the residents of the three areas to assess the characteristics of the areas and residents which cannot be expressed by statistical data. Five hundred households were selected for each area by random sampling. Then questionnaire sheets containing 24 questions were sent by mail and answer sheets of 732 (48.8%) were returned to us. This response ratio was rather high probably because it was just after the Kushiro-Oki Earthquake on January 15, 1993.

The results of the survey were examined carefully by taking simple and cross statistics. An example is shown in Table 8, in which damage estimation to one's own house is summarized. It is observed that the residents of Sumida anticipate much higher damage than the residents of the two other areas. The residents in Sumida probably cared much about soft soil and small and old houses in the area. Fires following an earthquake are also highly anticipated in Sumida, which explains the highest participation rate of fire insurance (according to the questionnaire survey, 81% in Sumida, 65% in Azabu and 74% in Tsurumaki).

5. MICROSCOPIC EARTHQUAKE DAMAGE SCENARIO

Recently, earthquake damage scenarios have been considered useful for disaster mitigation since they can give vivid image of disasters to both professionals and ordinary people. However, a consensus has not been reached about the form of scenarios. In this study, three different types of scenarios are considered. The first one consists of tables listing incidents and activities after earthquakes chronologically based on the damage assessment and lessons learned from previous earthquakes. How to visualize the contents of the tables is the key to this style. The second one is "story simulation", like a movie scenario. This style may be most easily understood by residents, but only few individuals can appear in a scenario. Hence, several representative scenarios must be prepared for different areas and different compositions of family. The third one is an interactive TV game style. We are now developing such software. In any case, to simulate surrounding situations as well as individual incidents is an important task for microscopic earthquake scenarios.

Table 8 House damage anticipated by residents (%)

Damage category	Azabu	Tsurumaki	Sumida
no damage	0.0	1.5	1.3
little damage	29.8	26.2	18.1
considerable damage	50.2	51.5	38.4
severe damage	19.2	18.9	38.8
no answer	0.8	1.9	3.4

(a) 2 hours after (b) 4 hours after

Figure 7 Results of fire-spread simulation in Sumida

6. SUMMARY

This paper presents a methodology of earthquake damage assessment with the enhanced use of characteristics of local areas. Three residential areas in Tokyo Metropolis are selected as study sites. The geographic information system (GIS) is fully employed to visualize, analyze and express the seismic vulnerability of local areas. Various data characterizing the areas, e.g., soil conditions, buildings and residents, are collected and a database is created. A scenario earthquake is considered for the three areas and building damage and associated fires are estimated. Considering the results of the damage assessment together with the results of the questionnaire survey among the residents on disaster preparedness, earthquake damage scenarios are developed. This kind of approach may give a clearer image of urban disasters to local residents as well as professionals of disaster mitigation.

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