ESTIMATING ABILITY OF ACCOMMODATION SHELTERS FOCUSING ON ACCESSIBILITY AND CAPACITY FOR EARTHQUAKE DISASTER PREVENTION USING BASIC SURVEY OF URBAN PLANNING

- A Case Study of Kanazawa City, Japan -

○NGUYEN Dinh Thanh*1 SHEN Zhenjiang*2,
HONDA Kyohei*1, KAWAKAMI Mitsuhiko*3,
KOBAYASHI Fumihiko*4

Keywords： Accommodation shelters, capacity risk, earthquake disaster prevention, and evacuation distance.

1. INTRODUCTION

A mega-disaster will result in an enormous number of evacuees staying in evacuation center for a significantly long time. During the disaster relief period of Great East Japan Earthquake (GEJE) 2011, over 120,000 houses were totally damaged and there were more than 470,000 people who evacuated at more than 2,400 shelters. Moreover, it is said that there was a lack of sufficient supplies of food, water, blankets, electric power, etc. Therefore, from the lesson of GEJE, many prefectures and municipalities all over Japan are conducting ex-post evaluations to assess the locations and number of evacuation shelters and the adequacy of essential supplies, such as food and drinking water, electric power, etc. at these shelters. Besides that, because the damage caused by earthquake of varying magnitude is uncertain and unpredictable, disaster preparation and planning for disaster prevention are extremely necessary in Kanazawa City in specific in Japan in general.

Until now, a lot of research on the field of earthquake disaster prevention have been conducted. Some research suggested formulas for predicting number of refugees based on seismic intensity (Kimura et al., 2004) or number of collapsed, burnt down buildings, and the population of collapsed and burnt down buildings (SHAO et al., 2012). Chou et al. (2013) determined displaced citizens for short-term shelters by considering relocation ratio, damaged houses, household income, house ownership and ages. In these research, number of people of each building was an average population of building in each machi or each district. In another word, number of people of each building in the same machi or district is equal. Besides that, there are some research focusing on estimating shelter capacity and shelter safety. Xu et al. (2008) calculated four types of shelters capacities according to different scenarios and then compared them in order to propose four types of shelters accommodation capacity risks while Chou et al. (2013) found out the districts with insufficient shelter capacity according to three simulated seismic scenarios by comparing predicted displaced citizens at each shelter and that shelter's capacity in each district. In addition, Tai et al. (2013) based on the calculated score of three composite indices that were integrated from ten independent indices individually related to road network in order to assess shelter safety. From above research, there was no research on simulating evacuees' shelter choice based on road network. Moreover, most of authors required refugees to go to designated shelters in their school districts, where may not be the nearest one from the refugees' houses.

The aim of this study is to estimate ability of accommodation shelter focusing on accessibility and capacity for disaster prevention during earthquake relief period. Our contribution to the existing literature is that by using open data, namely basic survey of urban planning including road network data, building data, population data, and data on evacuation shelter locations in Kanazawa City, we represent a method to calculate population of each building and simulate choosing nearest shelters based on the road network in order to calculate number of evacuees and capacity risk at each shelter. This kind of simulation results can provide local government with a useful visualized reference for improving evacuation plan. Besides that, a map of evacuation distances from each shelter to buildings (households) was developed in three categories of distances with 500m, 1000m, and 2000m respectively. Finally, research results were demonstrated by using Geographic Information System (GIS).

2. METHODOLOGY

ArcGIS software is employed as a tool for calculations and analysis, and Kanazawa City (Ishikawa Prefecture), Japan is considered as a case study.

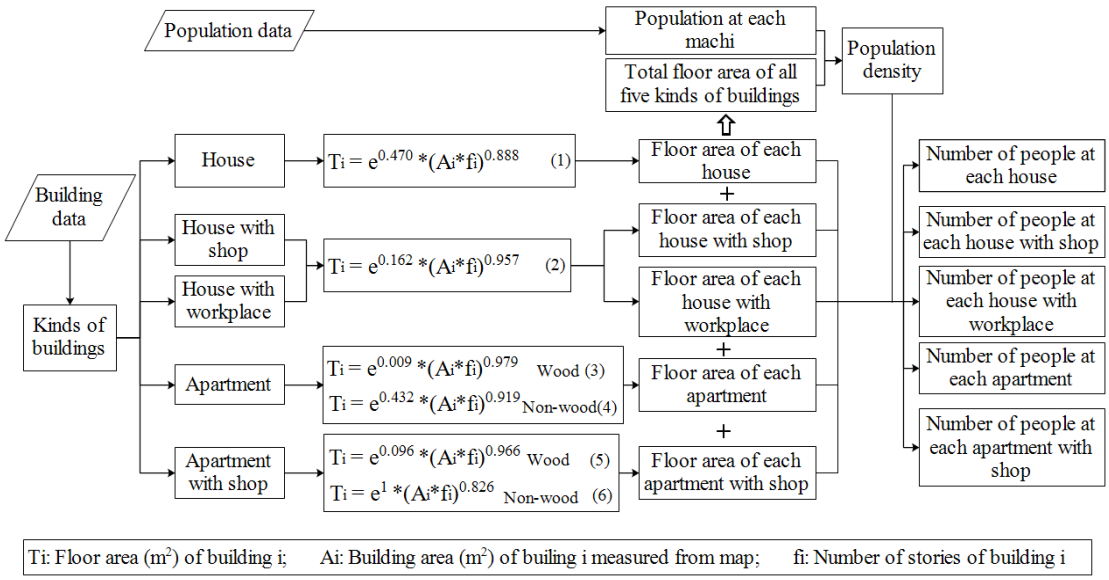

Fig.1- Flowchart representing a procedure for calculating number of people of each building

Data on basic survey of urban planning in Kanazawa City (building data (polygon data, 2013) and population data (polygon data, 2010)) are used for predicting number of evacuees with an assumption of seismic intensity. By using Network Analysis function of ArcGIS combining with road network data (polyline data, 2006) and data on locations of evacuation shelters (point data, 2006), we created a map of evacuation distance for evaluating accessibility from each shelter to households and simulated evacuees' shelter choice in order to calculate number of evacuees of each shelter.

From above results, estimation on capacity risk of each accommodation shelter is conducted by comparing the shelter's capacity and predicted evacuees.

3. CASE STUDY

Kanazawa City is the biggest and chief city in Ishikawa Prefecture. The City has 887 Chos covering 467.77 km^2, a total population of 462,478 (2010), and population density of 988.69 people/km^2. In the present, there are 497 evacuation shelters in Kanazawa that divided into two kinds, primary shelter (285 shelters including parks, squares, and open spaces) and accommodation shelters (212 shelters composed of elementary, secondary, and high schools, universities (116) and community centers and school's gyms (96)).

A recent large earthquake in Ishikawa Prefecture was Noto Peninsula Earthquake (in the Noto peninsula region in the northern part of Ishikawa Prefecture) that occurred in March 2007. In this event, the earthquake shook Wajima City with a seismic intensity of 6 upper JMA (6.7M) that was also the largest seismic intensity in Wajima City while Kanazawa City (epicentral distance 80km) also reached seismic intensity of 4 and had no damage as the website in reference No.7. Until now, although Kanazawa City has not shaken by large earthquakes, because this city is located in the active Morimoto-Togashi fault zone, a large earthquake could occur.

4. PREDICTING NUMBER OF EVACUEES

After an earthquake, most people whose houses are damaged not only evacuate at shelters but also go to their relatives or their friends' houses. It is said that more than 65% of people with damaged houses went to shelters while other around 35% lived with their relatives and friends' houses. Because the number of evacuees and number of damaged buildings have mutual relationship, in this study, we determined number of evacuees based on the number of people at each building and number of damaged buildings. We made some assumptions for calculation as following. 1) The earthquake occurred at night (4 AM); 2) From 21 kinds of buildings with different functions of building data, there are five kinds that most people always stay at night that are house, house with shop, house with workplace, apartment, and apartment with workplace. Therefore, we assume that all people live in these five kinds of buildings. 3) According to a material about assessment of earthquake disaster from website of Kanazawa City as reference number 8, buildings with an area less than 20m^2 is not considered for predicting building damage due to earthquake. Therefore, basing on the result on the building area of each building, we ignored buildings that have an area less than 20m^2; 4) All occupants in damaged buildings will evacuate; 5) People in 65% of all damaged building will go to the evacuation shelters; 6) There were two seismic event scenario with intensity of 6.5 JMA, and 7.0 JMA; 7) People who want to stay at evacuation shelters are required to go to the nearest one; 8) 112 of 116 schools that include primary,

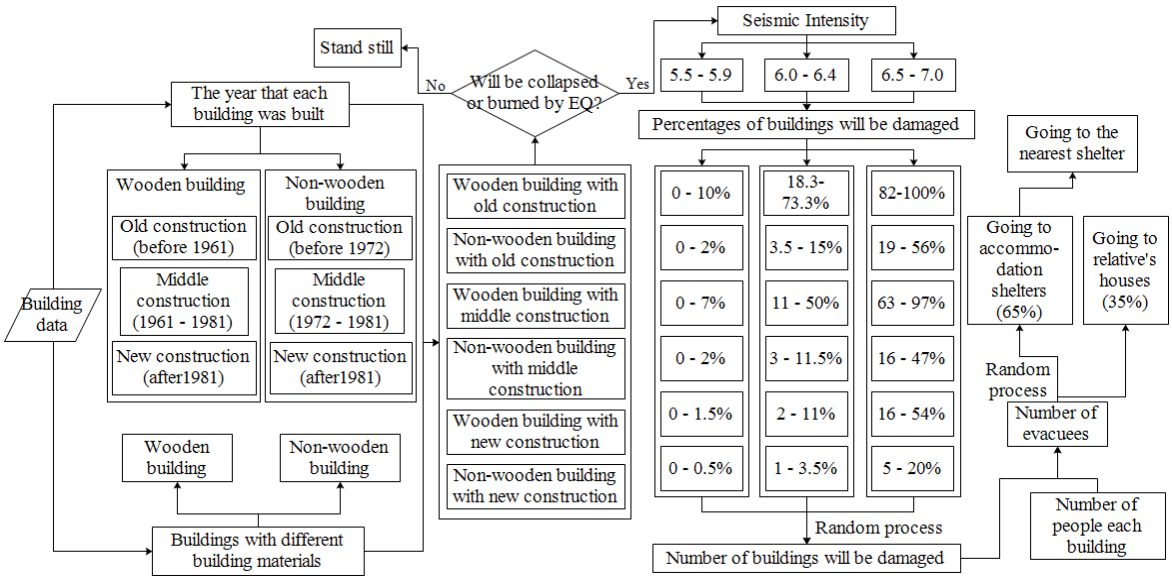

Fig.2 - Flowchart representing a procedure for predicting number of damaged buildings

secondary, and high schools, and universities are considered as accommodation shelters (other 4 shelters are outside of the road network); 9) There is no traffic congestion and roads are wide enough to go through by people.

4.1. Calculating number of people of each building

As mentioned in introduction part, in this research, we suggested the way for calculating number of people of each building based on population data, building data. Ohba (2000) established formulas to calculate the gross floor area of five kinds of buildings that are house, house with shop, apartment, apartment with shop, and business facilities based on their building area and building height. In this research, we applied the formulas of the first four kinds of buildings for calculating gross floor area. Moreover, we also assumed that buildings that are houses with workplace have a same formula as buildings that are houses with shop. The formulas for calculating gross floor area developed by Ohba are showed as (1) to (6) in figure 1. Besides that, for calculating building area of each building, we used "Geometry Calculate" function in ArcGIS software while the number of stories of each building is known as one of attributes of building data. The detail procedure for calculating population of each building is presented in figure 1.

According to a result on population of each building, 1) There are 458,397 people living in five kinds of buildings; 2) The number of people at each building depends on floor area of each building and population of the Cho where it is located, so buildings with the same floor area have different number of people; 3) There are some buildings with no people.

4.2. Calculating number of damaged buildings

From the attributes of building data, we divided all buildings into six types based on building materials (wood and non-wood), and construction era (new, middle, and old construction) that are wooden and non-wooden buildings with new construction, wooden and non-wooden buildings with middle construction, and wooden and non-wooden building with old construction. Then, by using statistic data (Naikakufu, 2005) on percentages of damaged buildings according to different seismic intensities in past earthquakes combining with six types of buildings, we predicted number of damaged buildings (Figure 2).

Table 1 – Number of damaged buildings and evacuees according to different seismic intensities

	Total	Intensity of 6.5		Intensity of 7.0	
		Damaged buildings	Evacuees	Damaged buildings	Evacuees
House	125904	41601	81661	84371	173640
Apartment	10289	1483		4106	
House with shop	8467	2897		5535	
Aapartment with shop	1388	153		462	
House with workplace	2114	752		1416	
Toal	148162	46886		95890	

Besides that, we also used a tool named select random in ArcGIS software for selecting number of damaged buildings randomly based on statistic data on percentages of damaged buildings. Finally, the number of evacuees is calculated based on the randomly selected damaged buildings (table 1) and it is considered as an input data for a simulation of shelter choice in section 5.1.

5. ESTIMATING ABILITY OF ACCOMMODATION SHELTERS

5.1. Estimating capacity risk of accommodation shelters

In this research, capacity risk of a shelter is determined

by comparing the number of evacuees and capacity of that shelter and it is divided into four levels, safe, low risk, moderate risk, and high risk according capacity excess of evacuees. A simulation for choosing nearest shelters based on the road network is conducted in order to calculate number of evacuees at each shelter. The reasons we conducted the simulation using the shortest distance is that firstly, there are some disadvantages by using school district. For example, people will take longer distance to go to the designated shelters in their school districts. Moreover, in Kanazawa City, there are a lot of school districts where people live in a same machi but belong to different school districts, such as, Izumi school district, etc. Secondly, from our thought, during the emergency period, most people may want to go to the nearest shelter for their safe firstly, and then they may go to the designated shelter in their school district later. Finally, we hope our thinking may support to local government as a reference for solving disadvantages of the present evacuation strategy that people are required to evacuate at shelters in their school districts. Besides that, a capacity of an accommodation shelter is calculated by dividing the affordable living area of each shelter by the necessary living area per capita (Xu et al, 2006). Data on area of shelters are available and collected from official website of Kanazawa city as the website in reference No.12. Moreover, we assumed that each evacuee requires at least 3 m^2 of shelter space. The procedure for estimating capacity risk is represented as Figure 3.

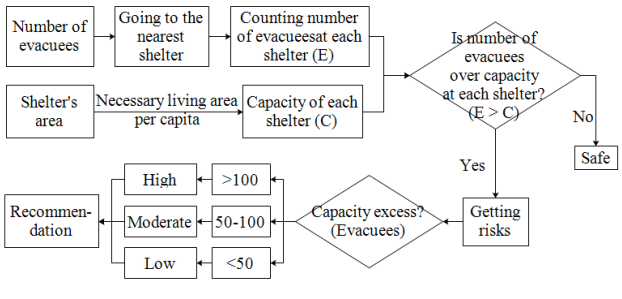

Fig.3 - Flowchart representing a procedure for estimating capacity risk of accommodation shelters

5.2. Estimating accessibility to accommodation shelters

During the disaster, the accessibility from households to shelters plays an importance for evacuation planning. Moreover, all the households should be aware of which shelter they should go to or how far or how long from their houses to the nearest or designated shelter before a disaster occurs. By using Network Analysis function in ArcGIS software, this study created a map of evacuation distance from each shelter to buildings (households) in three categories of distances with 500m, 1000m, and 2000m respectively based on the road network (Figure 4). Basing on this map, all residents could know which evacuation shelters they should go as well as the distance from their houses to those shelters.

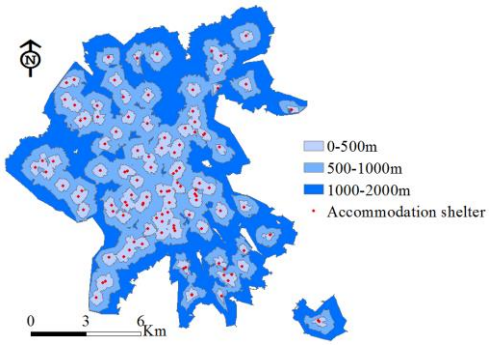

Fig.4 – Categories of evacuation distances in Kanazawa City.

6. RESULT ANALYSIS AND DISCUSSION

In the first seismic event scenario with an intensity of 6.5 JMA, there were 79 shelters which are safe (Figure 5). 75 of them have space for more 240 to 3400 evacuees. No evacuee chose other four shelters that are shelter 29, 54, 66, and 79 because there are shelter 10, shelter 80, 81, 82, shelter 8, and shelter 76 located on the way to these four shelters respectively. Moreover, we have not obtained information about area of shelter 29, 54, and 66 while capacity of shelter 79 is 948. There are 33 shelters which capacities are not insufficient. 32 of these have capacity as 0 because we have not obtained their areas yet. However, the evacuees of these shelters are only from 11 to 1170 and these shelters may have more spaces for such number of evacuees in the real. Another shelter with insufficient capacity is shelter 57 which capacity is 2668 while evacuees are 2743. However, there are 3 community centers near to shelter 57, so the exceeded evacuees may stay at these community centers.

Table – 2 Number of buildings and people according to different categories of evacuation distances of 112 accommodation shelters

Evacuation distance	0-500m		500-1000m		1000-2000m		>2000m	
	Buildings	People	Buildings	People	Buildings	People	Buildings	People
House	43367	113483	56890	150049	23841	62215	1806	3338
Apartment	4076	37367	4977	44981	1210	10927	26	188
House with Shop	3352	6796	3965	7743	1087	1972	63	112
Apartment with Shop	607	6187	689	7714	91	960	1	3
House with Workplace	700	1478	926	1926	445	870	43	70
Percentage	35.2%	36.1%	45.5%	46.3%	18.0%	16.8%	1.3%	0.8%

In the second scenario, the number of damaged buildings and evacuees is two times more than those in the first scenario because of severity of intensity of 7 JMA. There are 54 shelters that got risk and 32 of them are the same as 32 shelters in the first scenario which capacity is 0. In other 22 shelters, the number of evacuees exceeded capacity. Besides

that, number of shelters that are safe is 58 and four of them have no evacuee that are same as in the first scenario.

A result on accessibility to 112 accommodation shelters in Kanazawa City that indicates percentages of buildings and people in each category of evacuation distance is showed in table 2. From above result, there are a lot of buildings (20% of all buildings) and people (18% of population) who need to take more than 1000m to go to the shelters. Therefore, it is necessary to designate more shelters in order to decrease residents' evacuation distance. In the present, local government of Kanazawa city also designated 96 community centers as accommodation shelters in the case of lack of accommodation shelters. If we consider the community centers as accommodation shelters, the evacuation distance in Kanazawa City may be shorter.

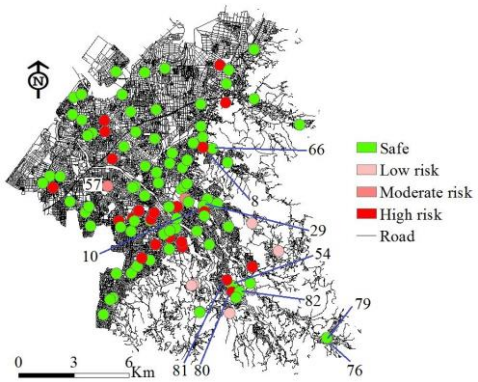

Fig.5 – Capacity risk of 112 shelters by seismic intensity of 6.5 JMA

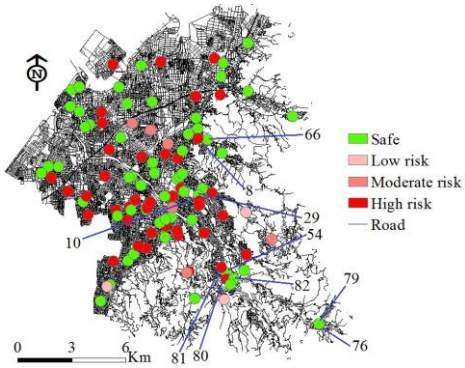

Fig.6 – Capacity risk of 112 shelters by seismic intensity of 7JMA

7. CONCLUSIONS AND FURTHER RESEARCH

This study suggested a method for calculating population of each building as well as simulating the evacuees' nearest shelter choice in order to estimate capacity risk and accessibility at each accommodation shelter. The results showed that in the case of intensity of 6.5 JMA, it seemed that shelter capacity is sufficient for evacuees. While in the case of intensity of 7, number of shelter getting risk is 22 shelters. For the accessibility to accommodation shelters, it is necessary to consider community centers in evacuation plan in order to decrease residents' evacuation distance. We hope the above results can provide local government as useful reference for solving disadvantages of current evacuation strategy.

For the further research, we will focus on the solutions for solving the disadvantages of current evacuation plan in Kanazawa in order to support local government for improving the evacuation plan.

REFERRENCES

1) Federica Ranghieri and Mikio Ishiwatari. *Learing from megadisasters – Lessons from the great east Japanese Earthquake*. The world bank, Washington DC. Chapter 18: Evacuation Center Management, pp155-159.

2) Reo KIMURA, Haruo HAYASHI, Shigeo TATSUKI, Keiko TAMURA. *Development of The Method of Estimating The Number of People at Evacuation Center in Case of Urban Earthquake Disaster*. 13th World Conference on earthquake engineering. Vancouver, B.C., Canada, August 1-6, 2004, Paper No. 1036

3) Chunhao SHAO and Takeyoshi TANAKA. *Prediction of Refugee Population in School Districts*. Journal of Natuaral Disaster Science, Volume 33, Number 1, 2012, pp37-48.

4) Jui-Sheng Chou, Yu-Chen Ou, Min-Yuan Cheng, Min-Yuan Cheng, Chen-Ming Lee. Emergency shelter capacity estimation by earthquake damage analysis. Nat Hazards (2013) 65: 2031-2061 DOI 10.1007/s11069-012-0461-5

5) Wei XU, Norio OKADA, Michinori HATAYAMA and Yukiko TAKEUCHI. *A Model Analysis Approach for Reassessment of The Public Shelter Plan Focusing both on Accessibility and Accommodation Capacity for Residents – Case Study of Nagata Ward in Kobe City, Japan*. Journal of Natural Disaster Science, Volume 28, Number 2, 2008, pp85-90.

6) Cheng-An Tai, Yung-Lung Lee. Urban Disaster Prevention Shelter Vulnerability Evacuation Consideration Road Network Characteristics. Journal of Civil Engineering and Architecture, 2013, Volume 7, No. 5 (Serial No. 66), pp. 609 – 615.

7) https://www.eeri.org/lfe/pdf/japan_noto_eeri_preliminary_report.pdf 2015/05/30

8) http://www4.city.kanazawa.lg.jp/data/open/cnt/3/14047/1/s2.pdf. 2014/07/30

9) Toru Ohba. Estimation of the gross floor area from building area and the building height.都市計画論文集，第 35 号，pp.1033-1038, 2000 年 (in Japanese)

10) 内閣府，首都直下地震に係る被害想定手法について，2005 年 2 月 25 日一部改訂

11) Wei XU, Norio OKADA, Michinori HATAYAMA and Chunyang HE. *Conceptual Model of Shelter Planning Based on The Vitae System*. 京都大学防災研究所年報、第 49 号B 平成 18 年 4 月(Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 49B, 2006)

12) http://www4.city.kanazawa.lg.jp/data/open/cnt/3/520/1/1-5kyouiku-kankyou.pdf 2014/12/17

＊1 Graduated Student, School of Environmental Design, Kanazawa University

＊2 Professor, School of Environmental Design, Kanazawa University, D.Eng.

＊3 Emeritus Professor, School of Environmental Design, Kanazawa University, D.Eng.

＊4 Assoc. Prof, School of Environmental Design, Kanazawa University, D.Eng.

都市計画基礎調査データを用いた地震発生時の避難場所の アクセシビリティと収容力の評価

- 金沢市を事例として-

○グエン ディン タン*1 沈　振江*2
本田匡平*1　川上光彦*3　小林史彦*4

キーワード：避難場所、収容力、地震防災、避難距離

概要:

本研究は、都市計画基礎調査と防災マップ、すなわち金沢市のオープンデータを活用した研究であり、都市計画基礎調査には、道路網データ、建築データ、人口データがあり、防災マップに関して避難場所のデータがある。本稿では、これらのデータを用いて、将来に発生する地震を想定し、災害の危険度評価を通して、地震発生時の避難者数を推測し、避難場所の防災性能を評価することを目的としている。具体的には、この研究は、異なる震度によって、建物構造や築年数によって建物の倒壊数を推測し、さらに避難者数を推測する方法を検討する。避難者数を推測するには、地震被害を受けた建物の倒壊数とそれらの場所を基に、避難者が避難場所を選ぶためのシミュレーションを行い、個々の避難所への避難者数をまとめることにする。そして、個々の避難所から建物（家庭）までの避難距離は、それぞれ 500m、1000m と 2000m の 3 段階にし、避難場所がカバーできる範囲と避難者数の推測を行った。また、防災マップの関連データにより、避難場所の収容能力を把握し、推測した避難者数との比較により、それぞれの避難所の防災性能を評価し、その結果を GIS に可視化する。

本研究の結果は、市街地における地震防災のための基礎的な研究として、都市計画基礎調査のデータを活用する可能性を示したものである。

＊1　金沢大学大学院環境デザイン学専攻　大学院生
＊2　金沢大学環境デザイン学系　教授
＊3　金沢大学環境デザイン学系　名誉教授
＊4　金沢大学環境デザイン学系　講師