AN ANALYSIS TO MANAGE THE CURRENT CONDITIONS OF EVACUATION ROUTES IN A HISTORIC PRESERVATION AREA: THE PROBABILITY OF STREET BLOCKADES

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Abstract

Historic preservation areas are particularly vulnerable to disaster because many people inhabit these areas. These areas contain wooden houses built close to one another. It can be difficult to manage widening narrow streets in these areas to prevent disasters. Therefore, it is crucial to develop two-way evacuation routes in historic preservation areas. This study attempts to develop two-way evacuation routes for a historic preservation area based on the probability of street blockade use. We chose to study Hamanaka Machi Hachihongi Syuku, which is located in Kashima City, Saga Prefecture, Japan. It was designated an important preservation district that includes traditional buildings under the Act for the Protection of Cultural Properties. First, we defined the probability of street blockade use in historic preservation areas by examining a street blockade for a normal city area created by the Tokyo Fire Agency. We examined streets less than 4 m in width, the structure of houses that lined those streets, and the distances from houses to main streets that were more than 4 m in width. Second, we calculated evacuation times from each house to final evacuation sites with the use of blockades and in cases with over 70% probability of street blockade use based on a multi-agent system. We also considered the rooms in which vulnerable people sleep. The results revealed: (1) In cases that did not use blockades, evacuations, including evacuations of vulnerable people, were completed in ten minutes (2) In cases with over 70% probability of street blockade use, some evacuations were not completed because they required the use of roundabout routes to avoid blockades. We discovered some fundamental problems involved in the management of evacuation plans developed to prevent large disasters that relate to the determination of appropriate streets to be blocked in the study area.

Keywords: Historic Preservation, Evacuation Routes, Calculation of Evacuation Time, Probability of Street Blockade, Vulnerable People

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1. INTRODUCTION

1.1 Background

Several researchers have studied numerous aspects of urban habitation areas' vulnerability to natural disasters. Urban earthquakes inflict serious damage on regions experiencing rapid population growth rates, as well as on developing countries undergoing urbanization (Torry 1980). During the design of post-earthquake evacuation methods for urban areas, it can be useful to consider multiple scenarios related to fire spread (Nishino et al. 2012).

Historic preservation areas are particularly vulnerable to disasters because they are inhabited by many people. In these areas, many wooden houses are located close to one another. It can be difficult to widen narrow streets in these areas to prevent disasters. Therefore, it is important to determine two-way evacuation routes for people who reside in historic preservation areas. To determine evacuation routes during large-scale disasters, the use of street blockades may be required. Although probability of street blockade (hereafter, PSB) was determined by the Ministry of Land, Infrastructure, Transport and Tourism (hereafter, MLITT) to evaluate street's vulnerability, in all likelihood, PSBs will be used in normal urban areas. Most streets located in historic preservation areas are narrower than 4 m in width. Therefore, these streets would not qualify for PSBs. During evacuation route planning for historic preservation areas, we must consider the use of PSBs on vulnerable streets that are narrower than 4 m in width or develop alternative solutions that do not involve street widening. In addition, all solutions should promote residents' abilities to rescue vulnerable individuals who reside alone or are bedridden. The authors of the current study examined fire danger in a particular study area (Mishima and Taguchi 2011) and examined evacuation route planning for historic areas (Mishima et al. 2013a, 2013b). However, maintenance methods for two-way evacuation routes located in historical preservation areas have not yet been clarified. In fact, no studies have examined the use of PSBs in historic preservation areas.

1.2 Aim of the study

Based on the circumstances mentioned above, this study aims to discover fundamental problems related to the establishment of a method that might be used to manage two-way evacuation routes that use PSBs in historic preservation areas.

2. METHODS

2.1 Study Area

The study area was Hamanaka Machi Happongi Shuku, which is located in Kashima

(a) Tile-roofed wooden townhouses.

(b) Nagasaki Road

Figure 1: Photographs of the study area.

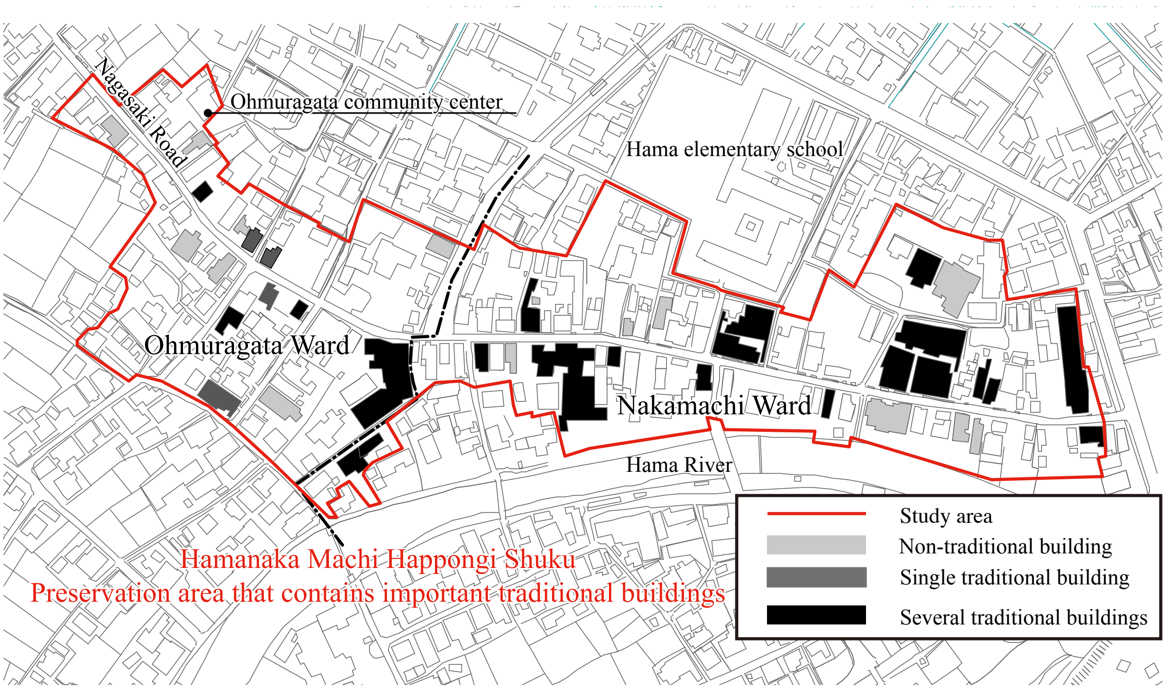

Figure 2: Preserved houses in the study area.

City, Saga Prefecture, Japan. In 2007, this area was designated an important preservation district that contained traditional buildings under the Act for the Protection of Cultural Properties. The district includes a sake-making town comprised of tile-roofed wooden townhouses and storehouses. The town is located alongside the Nagasaki Road, which was built to connect Kokura and Dejima with Nagasaki during the Edo Era (see Figure 1, (a) and (b), and Figure 2). In particular, the study area is extremely vulnerable to disasters. Therefore, it is important to protect its historic properties.

2.2 Method of Analysis

2.2.1 Flow of the Study

To achieve the goals of our study, we adopted the following procedures: (1) We determined the probability of the use of street blockades in a historic preservation area by creating an evaluation method that might be used for streets narrower than 4 m. in width. We also examined a PSB designed by MLITT, which has been used to evaluate the vulnerability of normal urban areas. (2) We applied the PSB to the study area to discover street vulnerability. (3) We calculated evacuation times from each house in the study area to a final designated evacuation site and evaluated each time.

2.2.2 Calculation of Evacuation Times

The primary analytic method used in this study was an examination of evacuation times required to travel from each house to one of the designated evacuation sites under present conditions in the study area. We used Sim Tread 1.0 for Vector Works 11 software to simulate the shortest evacuation routes, based on a multi-agent system. One significant point of this study is that the analysis was performed using software available in the marketplace.

3. PROBABILITY OF STREET BLOCKADES

3.1 Probability of Street Blockade Use as Determined by MLITT

MLITT defines PSB as follows:

a. In the case of a street that exceeds 8 m in width:

$$PSB = 0.0 \qquad (1)$$

b. In the case of a street that measures between 4 m and 8 m in width:

$$PSB = 1 - (1 - r^2)^n \qquad (2),$$

in which n is the number of buildings that face the street and r is the number of old buildings (i.e., the number of wooden buildings built before 1971 divided by the number of buildings that face the street.

c. In the case of a street that measures less than 4 m in width:

$$PSB = 1.0 \qquad (3)$$

This equation indicates that streets defined as less than 4 m in width which can easily be blocked during disasters such as large earthquakes.

3.2 Probability of Street Blockade Use in Historic Preservation Areas

Although all streets defined as less than 4 m in width can be entirely blocked using the method defined by MLITT, as mentioned above, streets located in historic preservation areas must be preserved. In other words, it is important to determine which particular narrower streets might be usable during disasters, rather than developing alternative methods.

We defined a PSB appropriate for use on streets that measure less than 4 m in width as follows:

$$PSB = 1 - (1 - r'^2)^{n'} * (4 / w) \qquad (4),$$

In which n' is number of buildings that face the street classified by width and r' is the number of old buildings that face the street classified by width.

Table 1: Probability of the use of street blockades (PSBs) in the study area.

Street No	w (m)	n'	r'	PSB
①-1	3.60	7.00	0.14	14.93%
①-2	4.00	5.00	0.60	89.26%
①-3	4.30	7.00	0.14	12.50%
①-4	2.00	5.00	0.60	100.00%
①-5	3.00	6.00	0.17	20.73%
①-6	3.50	2.00	0.00	0.00%
①-7	3.00	5.00	0.20	24.62%
①-8	3.50	11.00	0.18	35.33%
①-9	4.00	4.00	0.50	68.36%
②-1	4.10	2.00	1.00	97.56%
②-2	4.70	2.00	0.50	37.23%
②-3	10.00			0.00%
②-4	2.20	2.00	0.50	79.55%
②-5	4.20	11.00	0.64	94.92%
②-6	3.70	6.00	0.50	88.87%
②-7	3.50	2.00	0.00	0.00%
②-8	4.20	2.00	0.50	41.67%
②-9	2.90	4.00	0.50	94.29%
③-1	3.00	1.00	1.00	100.00%
③-2	4.00	1.00	1.00	100.00%
③-3	3.80	2.00	0.50	46.05%
③-4	1.78	1.00	1.00	100.00%
③-5	2.65	2.00	1.00	100.00%
③-6	4.00	9.00	0.44	86.20%
③-7	2.80	2.00	1.00	100.00%
③-8	1.68	2.00	1.00	100.00%
③-9	1.73	3.00	0.33	68.82%
④-1	1.60	2.00	0.00	0.00%
④-2	2.20	6.00	0.50	100.00%
④-3	4.70	13.00	0.50	83.08%
④-4	5.30	12.00	0.50	73.08%
④-5	1.70	2.00	0.50	100.00%
④-6	1.70	7.00	0.29	100.00%
④-7	3.00	2.00	0.00	0.00%
②-5	4.50	7.00	0.43	67.42%
	4.50	6.00	0.83	88.82%
③-6	4.00	2.00	0.50	43.75%
	4.70	7.00	0.43	64.55%

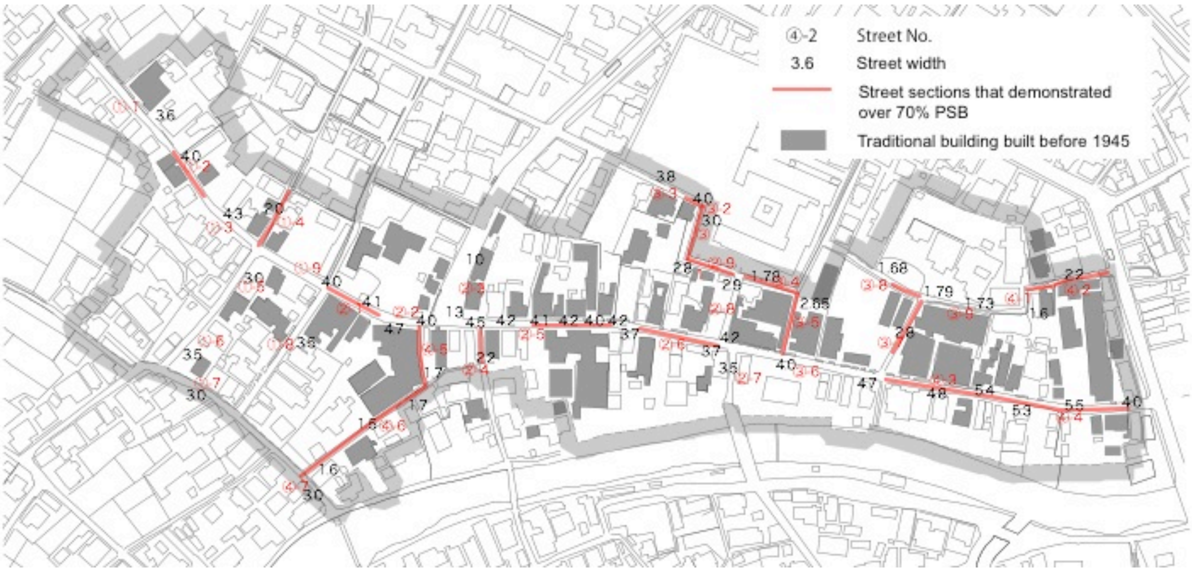

Figure 3: Street sections that demonstrated over 70% PSB in the study area.

3.3 Use of PSBs in the Study Area

3.3.1 Calculation of PSBs

We applied the PSB formula to the study area. Table 1 shows the results for PSBs by street. The widths of streets, n', r', and PSB are also indicated. We were able to obtain PSBs under the current conditions in the study area including PSBs for streets that measured less than 4 m in width.

3.3.2 Street Sections that Demonstrated Over 70% PSB

Based on the results of the PSB calculations, we determined street sections that demonstrated over 70% PSB. The results are shown in Figure 4. Colored buildings represent buildings constructed before 1945 (i.e., traditional buildings). Black numbers indicate the widths of street sections. Based on this figure, we determined that Nagasaki Road contained street sections that demonstrated over 70% PSB.

4. CALCULATION OF EVACUATION TIMES

4.1 Evacuation Goals and Routes

The final evacuation sites designated by Kashima City for this area are Hama Elementary School and Ohmuragata Community Center. The area has been divided into two smaller areas based on administrative wards (i.e., Nakamachi Ward and Ohmuragata Ward). The final evacuation site for Nakamachi Ward is Hama Elementary School. The final evacuation site for Ohmuragata Ward is Ohmuragata Community Center. In this case, we calculated evacuation times from each house to final evacuation sites both with and without the use of blockades. We will discuss the case of Nakamachi Ward because of page limits.

Previously, we conducted an interview survey to determine residents' perceptions of temporary safe places (Mishima et al. 2013b). We asked 48 residents to describe their perceptions of routes they might take to travel from their homes to temporary safe places in the study area. Similar to the previous survey, for the current research, we conducted an additional interview survey with the same interviewees (we only interviewed 35 residents because some residents had died or moved elsewhere) to learn about their family members and to determine their sleeping places. Based on the results of the survey, we calculated evacuation times from each member's sleeping place to a designated evacuation site. Family members equaled 67 people. They included 54 non-vulnerable people, 11 vulnerable people I (able to walk), and 2 vulnerable people II (unable to walk). To calculate evacuation times, we counted two evacuation routes for each person. Ultimately, we calculated 134 evacuation routes.

4.2 Fundamental Walking Pace

We calculated the evacuation times for non-vulnerable people, vulnerable people I (able to walk), and vulnerable people II (unable to walk). We defined their normal walking speeds based on Japanese verification methods used to determine safe evacuations from the first floor of a building. These methods state that a typical person's walking pace equals 1.3 m/sec. We also based our calculations on a previous study conducted by Horiuchi (1994). Therefore, we relied on the following speeds:

Non-vulnerable people	1.30 m/sec
Vulnerable people I	1.00 m/sec
Vulnerable people II	0.50 m/sec

4.3 Calculation Results

4.3.1 Without Blockades

In this section, we discuss the calculation results without the use of street blockades, as shown in Figure 4 and Table 2. We classified evacuation times into three categories: within seven minutes, within ten minutes, and over ten minutes, based on a fire engine's arrival time after a fire alarm sounds.

For non-vulnerable people, all evacuations, including one roundabout route, were completed within seven minutes. For vulnerable people I, all evacuations were also completed within seven minutes. For vulnerable people II, although we only assigned four routes, three routes were completed within seven minutes and one route was completed within seven and ten minutes.

Figure 4: Calculation results for evacuation times without the use of street blockades.

Table 2: Evacuation times without the use of street blockades.

		Under 7 min.	7 – 10 min.	Over 10 min.
Non-vulnerable	Direct	107	0	0
	Roundabout	1	0	0
Vulnerable I	Direct	21	0	0
	Roundabout	1	0	0
Vulnerable II	Direct	3	0	0
	Roundabout	0	1	0

4.3.2 With Blockades

In this section, we discuss the calculation results with the use of street blockades, as shown in Figure 5 and Table 3.

For non-vulnerable people, all evacuations, including 86 roundabout routes, were completed within seven minutes. For vulnerable people I, although fifteen evacuations were completed within seven minutes, seven evacuation routes that involved roundabout routes were not completed within seven minutes. Rather, they were completed within seven and ten minutes. For vulnerable people II, no evacuations were completed within ten minutes. This included one route that took more than ten minutes.

These results revealed the difficulties involved in evacuations in the study area that

Figure 5: Calculation results for evacuation times with the use of street blockades.

Table 3: Evacuation times with the use of street blockades.

		Under 7 min.	7 – 10 min.	Over 10 min.
Non-vulnerable	Direct	22	0	0
	Roundabout	86	0	0
Vulnerable I	Direct	5	0	0
	Roundabout	10	7	0
Vulnerable II	Direct	0	1	0
	Roundabout	0	2	1

demonstrated over 70% PSB because the evacuation routes involved roundabout routes caused by the use of street blockades. If we consider less than 70% PSB in these calculations, the results include additional street blockades and evacuation times increase to more than ten minutes.

These calculations were made based on current conditions, as well as on the number of residents' family members. Older family members will be more vulnerable. Sleeping places for vulnerable people are generally located on the first floors of buildings. Hence, we should take measures to improve building exits or create roundabout shortcuts to designated evacuation sites.

5. CONCLUSION

In this paper, we determined PSBs for a historic preservation area based on a PSB developed by MLITT. We considered one of the characteristics of this area, the widths of its narrow streets, to evaluate the study area's vulnerability. We also attempted to discover the area's fundamental problems related to evacuation planning. Calculations of evacuation times based on the probability of street blockade use have never been performed in previous studies, even in the study area. This research indicates one possible risk management strategy that could be applied to historic preservation areas.

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