FIRE RISK ASSESSMENT OF JAPANESE TRADITIONAL WOODEN DISTRICT BASED ON PHYSICS-BASED MODEL FOR URBAN FIRE SPREAD

A STUDY ON EFFECTIVENESS OF FIRE FIGHTING ACTIVITIES OF COMMUNITY RESIDENTS IN KYOTO SANNEIZAKA DISTRICT

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ABSTRACT

Kyoto Sanneizaka district is a traditional wooden area. As they are wooden, built in Japanese traditional manner, and built close together, they are inevitably vulnerable to fire. Thus, it is important to explore effective countermeasures against fire spread. Kyoto city disclosed a report on 'the Disaster Prevention Project for Sanneizaka Important Preservation District for Groups of Important Historic Buildings'. In the plan, they try to maintain fire safety through effectively functioning fire fighting organizations mainly consisting of community residents. The authors assessed performance of fire fighting activities by community residents through fire risk analysis using Monte Carlo simulation with physics-based model for urban fire spread. Fire risk assessment was carried out for two different assumed conditions at which fire fighting activities were / were not considered. The results show apparent effect of fire fighting activity on suppressing the spread of fires.

KEYWORDS: Urban fire, Group of historic buildings, Fire risk, Fire spread, Fire fighting

INTRODUCTION

Many beautiful, traditional urban areas remain in Japan. In order to preserve and inherit their historical and cultural properties, there has been activity in recent years to introduce framework for promoting such as 'Important Preservation Districts for Groups of Important Historic Buildings'. On the other hand, there is a problem that such urban districts are generally composed of traditional wooden structures which are vulnerable to fire. In general, countermeasures such as widening of narrow streets or reconstruction of decrepit houses, in order to improve fire safety. It is not desirable to take such approaches in an urban district of traditional construction from the viewpoint of cultural value preservation.

In the 'Important Preservation District for Groups of Important Historic Buildings', drawing up of a disaster reduction plan is required for maintaining fire safety. In many cases, the disaster reduction plan designs to maintain fire safety through organizing volunteer groups of fire fighters mainly consisting of community residents. In recent circumstances where more respect is paid to local characteristics, it is important to quantitatively assess the performance of firefighting activities by community residents (referred to as "community fire control").

Some assessment methods for firefighting activities have already been proposed and widely put into practical use[1-3]. These existing methods are commonly used in terms assessing firefighting ability. The basic idea is as follows; first, the outer circumference of the burning zone is simulated; and then a fire brigade is to take in charge of a certain range at the fire front. These methods are advantageous in evaluating the effect of firefighting based on empirical knowledge that is derived from the past firefighting operations.

However, it is known that building fires greatly differ in behavior according to various factors, such as the building of structural conditions, climate conditions, and the status surrounding fires which appears as the difference in the effect of water discharge accordingly. In order to make a disaster reduction plan using local characteristics, it is necessary to have a method to rationally assess the effect of countermeasures applicable to variety of fire situations. The physics-based model for urban fire spread developed by Himoto et al. [4,5] is capable of rationally assessing the performance of a firefighting operation by considering it as the consumption of latent heat along with the evaporation of water. In this study, the authors assess the fire risk in an urban district with special emphasis on community fire-control ability taken into consideration, using the physics-based model for urban fire spread developed by Himoto, et al. The Sanneizaka district of Kyoto city, an 'Important Preservation District for Groups of Important Historic Buildings' is chosen as the site of this case study. Fire risk is to be assessed for two different conditions: one that the firefighting activity is taken into consideration and the other not. Then the results are compared with the existing issues related to local fire-control ability, which should incorporate into a future disaster reduction plan.

DEFINITION OF THE FIRE RISK

In order to assess the effectiveness of fire safety measures, which reflects community fire-control ability in the disaster reduction plan, it is necessary to quantitatively evaluate the effectiveness of the measures before and after the implementation of measures and compare them. The calculation conditions should be treated carefully because fire spread behaviors in an urban area differs substantially due to uncertain factors, such as, position and time of the fire origin the direction and velocity of urban wind and even other weather conditions, and so forth.

In this study, the concept of fire risk analysis is introduced, and uncertain factors existing in an urban area are reflected upon the assessment. According to the general definition, the fire risk R is given as a product of the loss probability P and the loss L, as follows:

$$R \equiv \sum_{i=1}^{N} (P_i L_i) \qquad [1]$$

Here the subscripts i denotes a trial of the Monte Carlo simulation, and N is assumed fire scenarios. Wide-ranging factors, which influence the behavior of the fire spread, lead to virtually innumerable fire scenarios.

OUTLINE OF FIRE SPREAD MODEL[4,5]

In the physics-based model for urban fire spread developed by Himoto et al., an urban fire is regarded as an ensemble collective of multiple building fires. The prediction of individual building fire under the influence of other building fires leads to the prediction of the overall behavior of the urban fire spread. Thus, the model consists of: (1) a model for prediction of fire behavior inside the building, (2) a model for prediction of fire spread behavior between buildings, and (3) a model for firefighting activities by community residents.

(1) A Model for Prediction of the Behavior inside Buildings

To predict behavior of fire within a compartment, the concept of the one-layer zone model is adopted. In the one-layer zone model, the properties of compartment gas are regarded uniform regardless of the location. The effects of firefighting activities are incorporated into the equations for mass, energy, and the chemical species, as follows:

$$\frac{d}{dt}\left(\rho_i V_i\right) = \dot{m}_{F,i} + {}_{V}\dot{m}_{V,i} - \sum_j \left(\dot{m}_{ij} - \dot{m}_{ji}\right) \qquad [2]$$

$$\frac{d}{dt}\left(c_P \rho_i T_i V_i\right) = \dot{Q}_{B,i} - \sum_j \left(c_P \dot{m}_{ij} T_i - c_P \dot{m}_{ji} T_j\right) - \sum_j \dot{Q}_{D,ij} - \sum_j \dot{Q}_{W,ij} - \Phi_V \dot{m}_{V,i} L_V + c_P\left(\Phi_V \dot{m}_{V,i}\right) T_V \qquad [3]$$

$$\frac{d}{dt}\left(\rho_i V_i Y_{X,i}\right) = \dot{\Gamma}_{X,i} - \sum \left(\dot{m}_{ij} Y_{X,i} - \dot{m}_{ji} Y_{X,j}\right) \qquad [4]$$

The state equation is given by,

$$\rho_i T_i = 353 \qquad [5]$$

where, t is time, ρ is gaseous density, V is the volume of the compartment, $\dot{m}_F$ is the speed of combustible gas provision from the thermal decomposition of combustible materials, ϕ_V is the ratio of water actually evaporating into water discharged, $\dot{m}_V$ is water-discharge speed, and $\dot{m}$ is the amount of hot gas flowing through an opening. Also, c_P is the specific heat under constant pressure of the gas, T is the gas temperature, $\dot{Q}_B$ is the heat generation rate of the combustible gas, $\dot{Q}_D$ is the speed of heat reduction by radiation through the opening, $\dot{Q}_W$ is the speed of heat reduction through walls, L_V is the evaporative latent heat of moisture, T_V is the evaporating temperature of the moisture, Y is the mass fraction of the chemical species, $\dot{\Gamma}$ is the speed of the chemical species generation speed, and subscript X is the chemical species. The subscripts ij and ji indicate the direction of flow generated between the compartment i and its neighboring compartment j across an opening between them. Also, Σ refers to the calculation of a sum regarding all the borderlines between compartments. Here, the momentarily changing behavior of the fire in the compartment is predicted by the simultaneous solution of these equations.

(2) A Model for Prediction of Fire Spread between Buildings

Meanwhile, factors for fire spread between buildings are regarded as the following: (i) thermal radiation from external flame, (ii) temperature rise due to wind blown fire plumes, and (iii) firebrand spotting. Similarity rules, each verified by model experiments, etc., are used here to calculate the fire spread, with the result of prediction for fire in the compartment in the building as the input conditions. The fire is believed to expand when these factors act, and (a) the heat flux which is injected through the openings exceeds the limit value, (b) the temperature of wood-based armoring material exceeds the limiting temperature for ignition, and (c) firebrand with sufficient heat energy fly apart.

(3) A Model of Firefighting Activities by Community Residents

In general, one or more buildings burn in an urban fire. Therefore, the community residents are to choose a building as a target of their activity. Factors for such a choice can be roughly divided into two: external factors, such as the structure of the urban district and burning status of the fire; and human factors, such as judgment of the community residents engaged in the activities. In this study a two-step procedure is employed. First, (i) buildings which can be a target of the activity (potential buildings for the activities) are chosen based on the external factors, then (ii) buildings which are actually to be the target of the activities are specified based on the human factors.

(i) In the first step with the external factors, a building which fulfills all the conditions as follows becomes the potential building for the activities: (a) it is located within the reachable range of a hose from a water supply, (b) it is located on an irregular line of the outer circumference surrounding the burning buildings, and (c) the increase of its ambient temperature by thermal current is under a certain level. (ii) Then, when there are two or more potential buildings for the activities based on the external factors exceed the ability of the available firefighting equipment and resources, it is necessary to choose a target out of the potential buildings based on the human factors. This choice seems to be influenced by many factors, such as the status of the fire nearby, the experience of the firefighters, and the cooperation with other activity units. In this study, a building closest to the water supply is set as a target of the firefighting.

CASE STUDY

Outline of Sanneizaka Important Preservation District for Groups of Important Historic Buildings

Kyoto Sanneizaka district is part of an urban area formed on the slope at the foot of Higashiyama Mountains. Many wooden traditional building structures along the inclining paths, stone steps and alleyways offer an excellent historical landscape (Fig. 1). This district has also been prospering as a Kiyomizu temple town and is regarded as one of the most notable sightseeing spots in Kyoto city. On the other hand, the community is increasingly aging. Thus, there is a high possibility that both physical damage and human harm will expand at the time of a disaster. There also is the issue of evacuation and the safety of tourists who do not know the area well.

The authors decided upon an area for calculation for this study to assess fire risk (Fig. 2). The calculation area is about 1,000m in length both east to west and north to south, surrounded by Maruyama park to the north, by Higashiyama mountain to the east, by graveyards of the temple and shrine to the south, and by Higashioji-street with a 15m-width to the east. The total number of buildings is 2,045. In the figure, black indicates fire resistant buildings, and the other refers to wooden or mortar plastered wooden ones. This shows that most of the district is occupied by wooden buildings. Therefore, it is highly possible that a fire which has occurred in the district can momentarily spread and expand.

FIGURE 1. The historical landscape of Kyoto Sanneizaka Important Preservation District for Groups of Important Historic Buildings

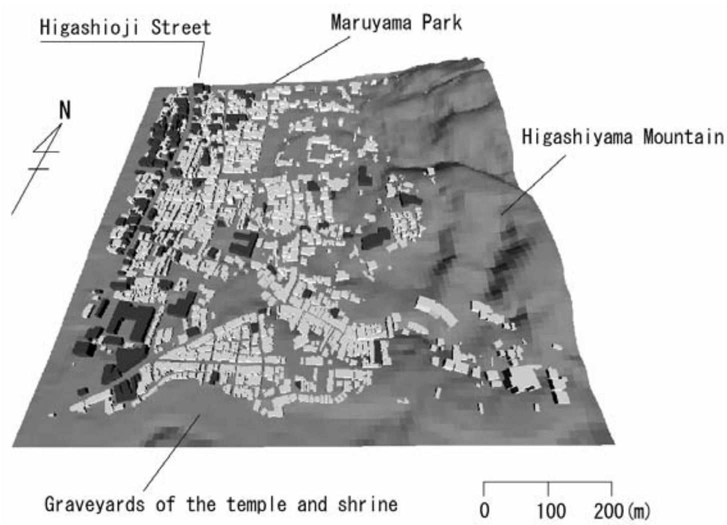

FIGURE 2. The area for calculation for this study, Kyoto. Black indicates fire resistant buildings

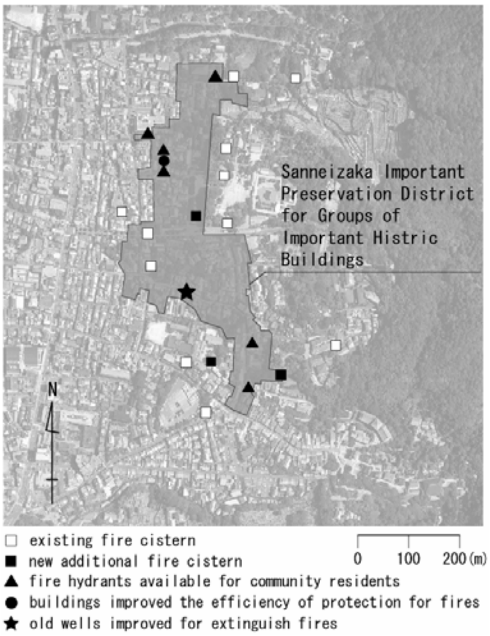

FIGURE 3. A plan to build additional facilities and equipment for disaster reduction, part of the 'Disaster Reduction Project of the Sanneizaka Important Preservation District for Groups of Important Historic Buildings'

There is some restriction, however, in applying the usual urban fire-safety methods, such as widening of narrow streets or reconstruction of decrepit houses, in a district of historic buildings from the viewpoint of preserving the local characteristics. Thus, Kyoto city made the Disaster Reduction Project for the Sanneizaka Important Preservation District for Groups of Important Historic Buildings[6] in 1997 and is moving forward with disaster measures by paying attention to the district's unique characteristics. To be concrete, the project includes: 1) building a local disaster prevention center, 2) building a warehouse for disaster reduction equipment, 3) building earthquake-resistant fire cisterns, 4) building fire hydrants, 5) restoring old wells, and 6) improving the fireproofing of buildings along streets (Fig. 3).

Conditions for Calculation

In this study, the fire risk in an urban district with firefighting activities by community residents being taken into consideration is assessed, and the efficiency of the community fire-control ability against an urban fire is quantitatively evaluated. The fire risk is assessed both with and without firefighting activities being taken in consideration, and the results of two cases are compared.

The fire risk R is given as a product of the loss probability P and the loss L, as follows:

$$R \equiv \sum_{i=1}^{N} (P_i L_i) \quad [1]$$

Here, i express the fire to be simulated and N refers to the number of combinations of the event probability P and the loss L (fire scenarios). Due to the fact that there are wide-ranging factors, which influence the behavior of the fire, there are virtually innumerable fire scenarios. The fire risk R is calculated with the Monte Carlo simulation, setting the number of fire scenarios as N = 500, which makes the variation of the risk R, or the expected value, sufficiently small.

Uncertain factors which influence the fire spread behavior include: (1) the condition of the fire occurrence, such as the place and time, (2) climate conditions, such as outside air temperature, direction and velocity of wind, and rainfall level, (3) condition of the building, such as its structure, fireproof performance, and the situation of its openings, (4) human factors, such as firefighting activities and evacuation, and (5) shielding factors, such as fences, walls and trees. In this study, shielding factors (5) are excluded because their location and influence on the fire have not yet been deduced. The conditions for the calculations of (1) to (4) are described as below.

(1) Condition of the Fire Occurrence

It is necessary to comprehensively assess the influence by different places of an urban fire starting based on fire risk analysis. Therefore, among the buildings within the Sanneizaka Important Preservation District for Groups of Important Historic Buildings, the authors set the conditions per calculation as a fire starting at one place chosen in a random manner, and at a randomly decided time, from when the calculation is continued for 12 hours.

(2) Climate Conditions

It is known that the behavior of an urban fire spread is greatly influenced by climate conditions. The authors took into consideration the outside air temperature and changes in direction and velocity of urban wind. The climate conditions were analyzed as below, with climate data for normal years created based on the AMeDAS observation data between 1981 and 1995[7].

(2-a) Outside Air Temperature (OAT)

The time scale for an urban fire is between several hours and several days. Fig. 5 indicates the hourly change of mean outside temperature, OAT, in a day by season. Note that spring here covers March to May, summer from June to August, autumn from September to November, and winter from December to February. The change in OAT stays within a 10-degree centigrade range regardless of season. The influence of the change of OAT on the fire behavior can thus be regarded as comparatively small, so the mean temperature of a day of each season is used for the calculation.

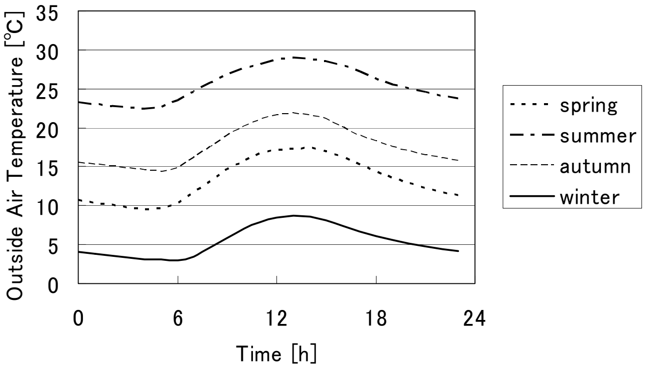

FIGURE 5. The hourly change of mean OAT

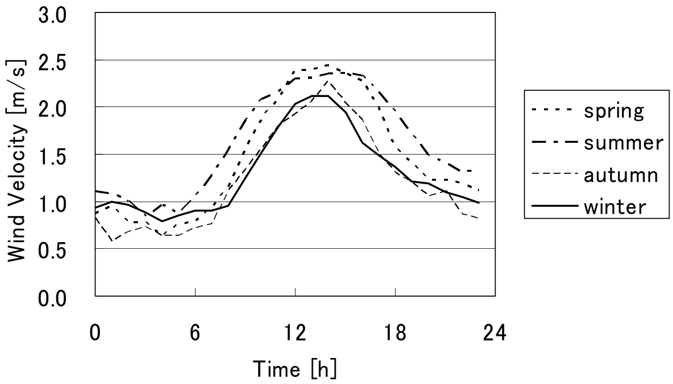

FIGURE 6. The hourly change of mean wind velocity

(2-b) Urban Wind

Regarding the velocity of urban wind, as well, the mean hourly change by season is evaluated as in the OAT above. The results are shown in Fig. 6. The mean wind velocity shows little change during a night regardless of season, and increases as the OAT increases to reach its maximum value after noon. The time that the wind velocity reaches its maximum is at 15 hours with about 2.44 m/s in spring, at 16 hours with about 2.37 m/s in summer, at 15 hours with about 2.27 m/s in autumn, and at 14 hours and 15 hours with about 2.12 m/s in winter.

It is empirically known that the higher the wind velocity, the greater the damage becomes. Therefore, it is estimated that the change in daily wind speed has a big impact on fire spread in an urban area. In this simulation, the condition is set to include the fluctuation from the mean value. To do so, the frequency of wind occurrence during the period when the wind velocity is maximum in a day is evaluated (Fig. 6). Then, with the maximum wind velocity in a day being randomly extracted based on the frequency of wind occurrence shown in Fig. 7, the variable ratio based on the mean value *r* (extracted value divided by mean value) is evaluated. The wind velocity setting is decided on by multiplication of *r* times the mean wind velocity in the calculation period shown in Fig. 6. The direction of the wind most frequently occurring in each hour is set as the wind direction of the hour.

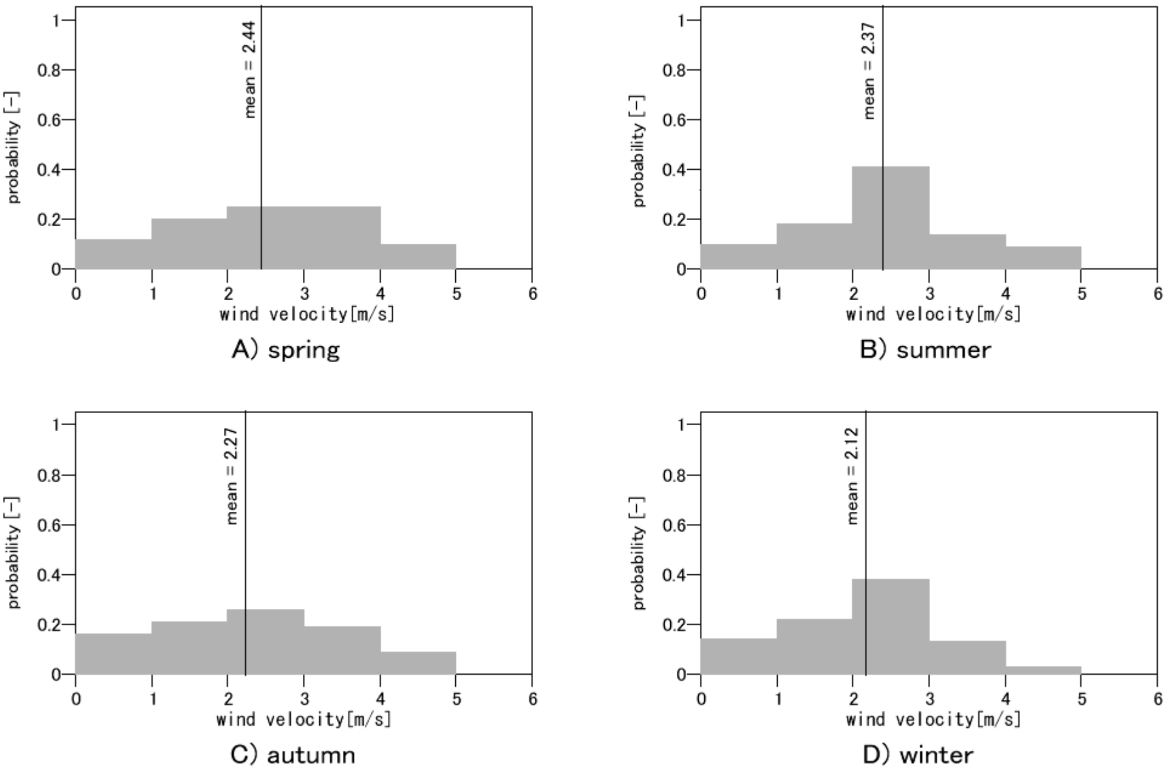

FIGURE 7. The probability of the maximum wind velocity occurrence

TABLE 1. The physicality values about construction structure

	Wooden Buildings	Mortar Plastered Wooden Buildings	Fire Resistant Buildings
Density of movable combustible	30 (kg/m^2)	30 (kg/ m^2)	30 (kg/ m^2)
Density of fixed combustible	100 (kg/ m^2)	60 (kg/ m^2)	30 (kg/ m^2)
Thickness (door)	3 (mm)		
Thickness (wall)	90 (mm)	90 (mm)	120 (mm)
Heat conductivity (door)	0.78×10^{-3} (kW/mK)		
Heat conductivity (wall)	0.15×10^{-3} (kW/mK)	1.3×10^{-3} (kW/mK)	1.3×10^{-3} (kW/mK)
Density (door)	2540 (kg/ m^3)		
Density (wall)	500 (kg/ m^3)	2000 (kg/ m^3)	2400 (kg/ m^3)
Specific heat (door)	0.77 (kJ/kgK)		
Specific heat (wall)	1.80 (kJ/kgK)	0.80 (kJ/kgK)	0.80 (kJ/kgK)
Burn-through time (door)	10 (min)		
Burn-through time (wall)	20 (min)	30 (min)	-
Heat of burn-through	2000(kJ/kg)		

(3) Condition of Building
GIS data based on aerial mapping photos and city planning maps are utilized to obtain building-related information, such as their shapes and number of stories, as well as the topography (vertical interval). Also, information about construction structure was obtained through field research and categorized into three areas: wooden buildings, mortar plastered wooden buildings, and fire resistant buildings, then prepared as input data. Physicality values indicated in Table 1 are added to the condition of the building for calculation. Each story of the building was regarded to have a single volume for the simulation, since it is not possible to know the internal layout of the building. The proportion of the area of the external opening to the area of the wall surface was estimated to be 30%, referring to existing field survey data[8]. It was assumed that the shape of the opening is rectangle, that its gravity center is shared with that of the wall surface, and that the height is uniformly 1.2 m.

(4) Human Factors
The purpose of this study is to assess the deterrence of community fire control against an urban fire spread. The starting time as well as the duration time of the firefighting activities is examined here. In the initial stage right after the outbreak of the fire, the result of the firefighting activity is decided on by how quickly the activity starts, since a fire increases in size with time. It is assumed that firefighting activity against a fire which occurred in a building within the district starts after the process below:

(i) The occurrence of the fire is recognized by the community residents.
(ii) Having recognized the fire, community residents procure equipment for firefighting and arrive at the water supply.
(iii) They stretch the hose from the water supply to the burning building to prepare for fire extinguishment.

The time between the fire outbreak and the start of water discharge, or activity starting time t_{init} , can be described as the sum of the times of the above-mentioned (i), (ii) and (iii), as follows:
(ii) and (iii), as follows:

$$t_{init} = t_1 + t_2 + t_3 \qquad [6]$$

Note that t_1 is the time to recognize the fire, t_2 is the time for residents to gather together, and t_3 is the preparation time.

(i) Time to Recognize the Fire
The necessary time for residents to recognize a fire is assumed to be 5 minutes after the fire outbreak.

(ii) Time to Gather Together
Residents who recognize the fire go to a place where firefighting equipment is stored. They then carry the equipment to the water supply to start the firefighting operation. It is assumed that the fire is recognized by residents who live near the building where the fire started, with the time between the point when the fire is recognized and the point when the firefighting activity actually starts is regarded as t_2 , the time necessary for them to gather together.

$$t_2 = \frac{\sqrt{2}(D_1 + D_2)}{v} \qquad [7]$$

Here, D_1 is the linear distance from the building of the fire outbreak to the warehouse of equipments, D_2 is the linear distance between the warehouse and the water supply, and v is the speed at which residents move (set at 2 m/s). $\sqrt{2}$ in the equation is a coefficient for the curves of streets.

(iii) Preparation Time
Residents, who arrive at the water supply work to connect the suction hoses and fire hoses and so

forth, then go to the building where the fire started. The time required here, preparation time t_3, is simulated as follows based on the results of a past survey targeting community-based organizations for disaster prevention[9]:

$$t_3 = 30 + 34x \ (s) \qquad [8]$$

Here, x is the number of hoses to be connected.

Water discharge against the burning building is assumed to continue from the activity starting time t_{init} until the water in the water supply is used up. This period is defined as activity-continuing time t_{ff}, and is calculated as below:

$$t_{ff} = \frac{V_V}{\dot{m}_V} \qquad [9]$$

V_V is water storage at the time of the fire breakout and $\dot{m}_V$ is the speed of water discharge. There is a portable fire pump, B3, prepared in the Sanneizaka District. The water discharge speed is assumed to be 8.33kg/s [10]. Fig. 8 shows the situation of the water supply and equipments for calculation.

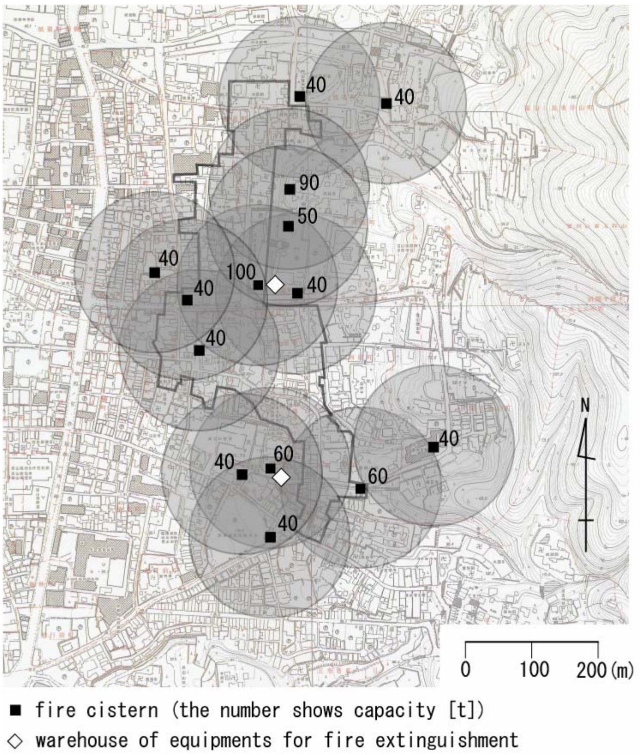

FIGURE 8. The situation of the water supply and equipments for calculation. The large circle shows the area to where the fire hoses are able to reach

CALCULATION RESULTS

The relationship between the loss L and the loss probability P as obtained by the Monte Carlo simulation is indicated in Figs. 9 and 10: (1) Fire risk in the case without firefighting activity is calculated as 464.8 buildings, and (2) fire risk in the case with firefighting activity is calculated as 102.0 buildings. The efficiency of community fire control is apparent.

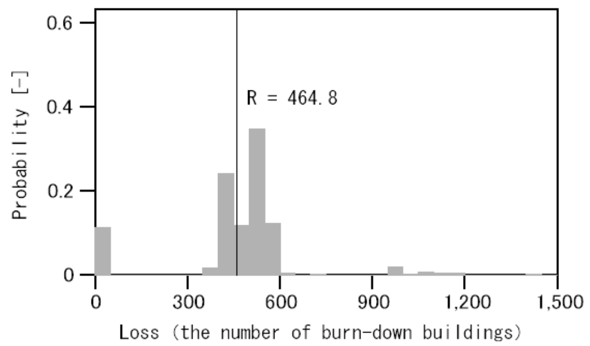

FIGURE 9. Fire risk in the case without fire fighting activity

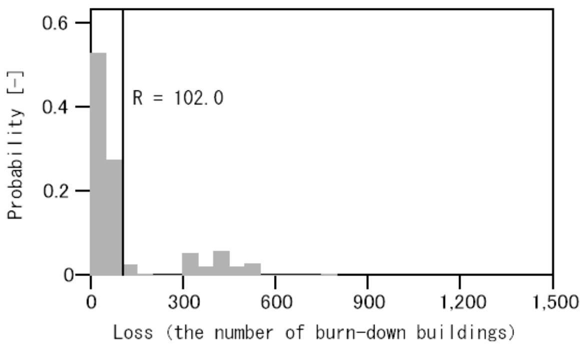

FIGURE 10. Fire risk in the case with fire fighting activity

DISCUSSION

When Firefighting Activity is Not Considered in Simulation

Fig. 9 indicates that the highest event probability appeared at L = 400-600 buildings, followed by L = 0-50 buildings. There was some possibility of large-scale fires of L = around 1,000 buildings.

This is believed due to the urban structures in and around Sanneizaka. Among 500 simulations, three representative cases which belong to the classification of L = 400-600 buildings, the range with the highest event probability, are presented in Fig. 11:

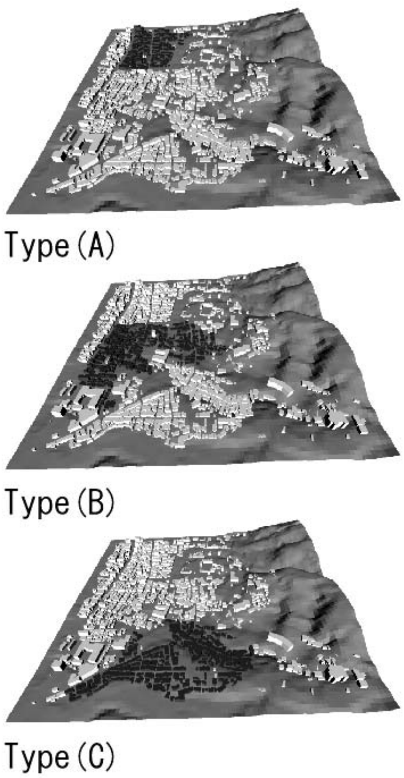

FIGURE 11. Three representative cases which belong to the classification of L = 400-600 buildings

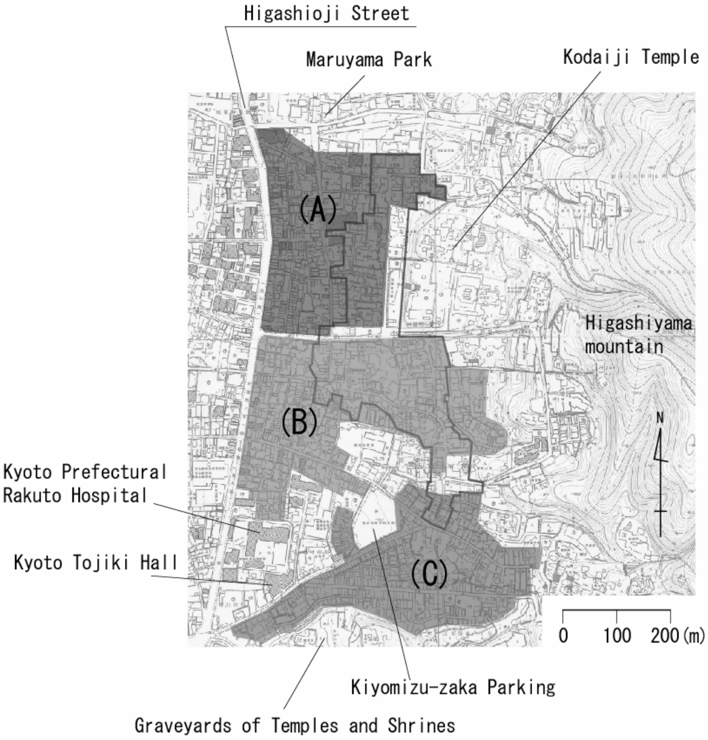

FIGURE 12. Three representative blocks divided from the viewpoint of fire spread

Fires were assumed to occur at a place within the Sanneizaka district that was chosen in a random manner. These are results of simulations of three cases where the event was assumed to have started: (A) around Ishibekoji in the northern part of the district, (B) around Yasaka pagoda and Ninenzaka in the central part of the district, and (C) around Sanneizaka in the southern area of the district. The black portion in the illustrations is the area where buildings were burnt out, and fire is not expected to spread any more even if the calculation is continued. This means that the district is roughly composed of three blocks from the viewpoint of fire spread. These are summed up in Fig. 12: (A) a block in the northern part is surrounded by Maruyama park to the north, by the Kodaiji temple compound and a bank to the east, by a road with a width of 10 m and vacant grounds to the south, and by Higashioji street with a width of 15 m to the west; (B) a block in the central area is surrounded by a road with a width of 10 m and vacant grounds to the north, by a forest of Higashiyama mountain to the east, by fire-retardant buildings such as Kyoto Tojiki Hall and the Kyoto Prefectural Rakuto Hospital and Kiyomizu-zaka parking lot to the south, and by Higashioji street with a width of 15 m to the west; and (C) a block in the southern part is surrounded by fire-retardant buildings and parking lots to the north and west, by a forest of Higashiyama mountain to the east, and by the graveyards of temples and shrines to the south. Each block consists of 400 to 600 buildings, and it was found that a fire stops at a road with a certain width, at vacant grounds or at fire resistant buildings.

The firebrand leaping from one block to the other by wind cause further fire spread. This is a rare case in which L = around 1,000 buildings are created. L = 0-50 buildings in some cases are thought to be the result of the starting place of a fire being chosen in a building that is surrounded by grounds, such as temple grounds.

When Firefighting Activity is Considered in Simulation

Fig. 10 shows that the highest event probability appeared in the L = 0-50 building group, and in most cases stayed at R = 102.0 or below. However, even though the event probability is low, it indicates that there is a case where a fire becomes large scale with the firefighting operation being conducted in vain. As is shown in Figs. 8 and 13, there are some spots in the district to where the fire hoses are not able to reach. The community residents' firefighting activity using a portable pump is believed to be effective at the beginning of a fire. It cannot be expected, however, to have any apparent effect in containing the spread of fire when the fire has expanded to a certain scale due to the fact the pump has only small water discharge ability (Fig. 13).

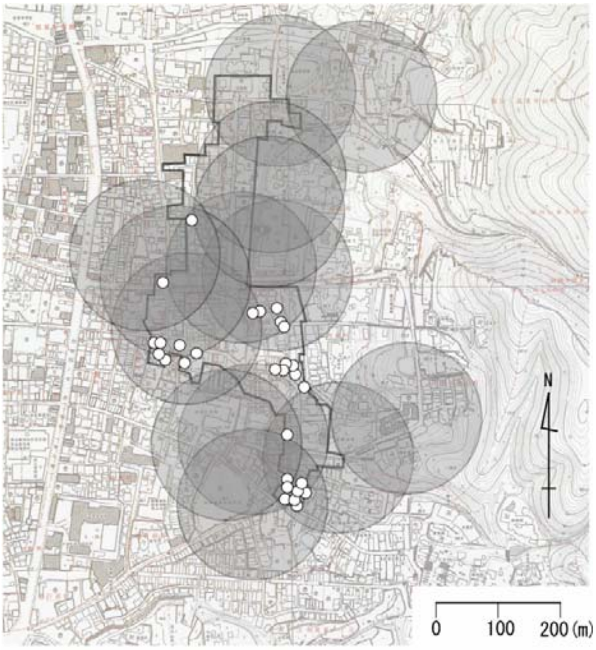

FIGURE 13. The relation between the area to where the fire hoses are able to reach (shown by large circle) and the spots where the fire, expanded large scale: L = 300-800, occurs (shown by small circle)

CONCLUSIONS

In this study, fire risk in an urban area is assessed utilizing the concept of fire risk analysis both with and without firefighting activities being taken into consideration. In general, it is known that the scale of the loss caused by an urban fire depends on various uncertain factors, such as the condition of the fire occurrence, climate conditions, building conditions, and human factors. The Monte Carlo simulation method is used for the calculation of the loss expectation value (fire risk) for many fire scenarios with the weather condition modeling based on AMeDAS data. This deduced, with a quantitative assessment, that community fire control is efficient; in other words, the fire risk is decreased when community residents are involved in firefighting operations. The following are future challenges and prospects.

(1) In this study the efficiency of the measures taking community fire control into consideration was quantitatively assessed. It was also reconfirmed that a fire stops at fire-resistant buildings and vacant grounds, as is generally believed, therefore the effectiveness of reconstruction or improvement of a building can also be evaluated. This can be a promising tool for drawing up a comprehensive and rational disaster-prevention plan.

(2) In the case study, it was recognized that in some cases (though rare), a fire may expand to become a large-scale disaster when the fire has started at a place which was not within the reachable range of fire hoses from a water supply and when the initial firefighting was not achieved. It is necessary to work out the effective locations for water sources in future measures.

(3) The results of the case study were gained only on the assumption that the fire is recognized right after its occurrence and the activity is smoothly carried out. In the case of simultaneous, multiple fires such as at the time of an earthquake, which is especially of concern nowadays,

various disturbances which prevent people from conducting their activities are expected to happen, such as the collapse of buildings, confusion around the point where the fire started, panic among the residents, and evacuation guidance for tourists unfamiliar with the district. The community residents are expected to actively take part in drills for evacuation, rescue and firefighting as actors for community fire control operations.

(4) It is also necessary, on the other hand, to formulate a localized model that pays attention to the actual status of community fire-control ability. In the assessment of simultaneous, multiple fires at the time of an earthquake, the potential influence of collapsed houses which block roads and paths as well as damaged buildings themselves on fire-spread behavior should be points of reflection.

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