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ESTIMATION OF DAMAGE DUE TO FIRES-REFUGE SIMULATION TECHNIQUE CONSIDERED FIRE BREAK OUT PROBABILITY ON AN EARTHQUAKE

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SUMMARY

In the city area where the wooden houses crowded, reduction of the fire damage due to an earthquake, and reduction of the human damage accompanying it are subjects. Estimation of the fire and human damage is indispensable to planning of an effective measure. I propose the simulation model using square grids and show the usefulness of this technique by applying it to an actual city area.

This technique is composed of three sub-models. These are the outbreak-of-fire sub-model considering the occurrence probability of fires, the spread-of-fire sub-model being expressed by the elliptic equation and the refuge-action sub-model being acquired from actual state of the past earthquakes.

The applied area is Ichikawa which has 56 square kilometers and a population of 430,000. The weather condition is 3m north wind. Outbreak-of-fire places are 83. Calculation is performed until 10 hours after an earthquake. The 100 outbreak-of-fire patterns are created by the Monte Carlo method. Then the spread-of-fires situation and the situation of people taking refuge are calculated from every outbreak-of-fire pattern.

As for any spread-of-fires situation, the rate of destruction area by fire in 10 hours is about 20%. On the average, 30 percent of all population begins refuge within 1 hour after an earthquake. The dead number varies greatly by the spread-of-fire situation. It is calculated that its average is 1782, its minimum is 234, and its maximum is 7027.

This technique can estimate the average fire damage and the average human damage accompanying it. The optimal fire-extinguishing activities corresponding to various fire patterns can be planned. As this technique can grasp the flow of the crowd in a specific place serially, safer guidance for a crowd can be concretely considered.

INTRODUCTION

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One of the characteristics of Japanese urban structure is the densely built-up areas with wooden buildings. Since such cities are prone to extensive damage from multiple fires immediately following an earthquake, they should consider various measures for preventing the outbreak of fire, arresting the spread of fire, providing evacuation guidance and securing refuges. A fire and evacuation simulation technique using grids to express the state of the area under analysis is effective for quantitative verification of these measures.

This paper consists of two parts: the first half explains three sub-models of the simulation technique; the fire outbreak sub-model considering the probability of the outbreak of fire, fire propagation sub-model obtained from case studies of past disasters and evacuation sub-model obtained from the evacuation behavior of people at the time of the 1923 Great Kanto Earthquake. The latter half quantitatively analyzes the damage caused by fire and the traffic of crowds following the spread of fire, by applying this technique to Ichikawa City in Chiba Prefecture which forms part of the Tokyo metropolitan area.

THREE SUB|MODELS COMPOSING THE SIMULATION TECHNIQUE

Outbreak-of-fire sub-model

As the outbreak of fire is a phenomenon involving numerous parameters, the sub-model for determining the points of fire outbreak is a grid model based on a stochastic technique.

It is assumed that all fires break out at grid points. A fire hazard value, which is an index to the relative probability of fire breakout, is assumed for each grid cell. The fire hazard value of a grid point is expressed as the representative value of the four cells surrounding the grid point (the average of the four fire hazard values). By substituting the total of the fire hazard values of all cells for 1, the fire probability corresponding to the fire hazard value is given to each grid point. The point of fire outbreak is determined based on the Monte-Carlo method, which generates random numbers, and the process is repeated for as many outbreak points as is considered necessary.

Spread-of-fire sub-model

The spread speed of fire is determined by the direction of the wind, the velocity of the wind and the population of wooden buildings [1]. Also, it is empirically known that fires in urban areas tend to spread in an oval form. Based upon these, the spread-of-fire sub-model is represented by a pseudo ellipse equation.

Beginning with calculation of the fire spread times at the eight grid points surrounding the fire outbreak point, the spread time is sequentially determined by the same calculation, until the spread time is obtained at all grid points (Fig. 1).

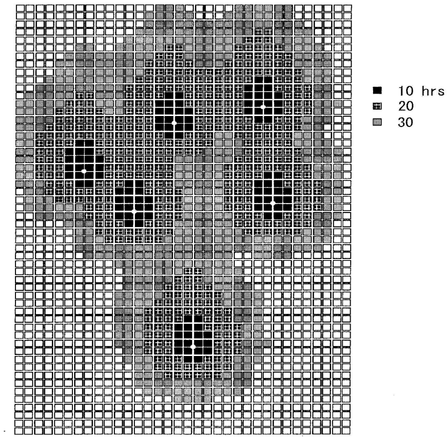

Fig. 1 6 fires expand in a 13 * 8 km^2 urban area having 0.5 wooden-building-to-land ratio by 6 m/s of southeast winds.

Refuge-action sub-model

The crowd refuge-action sub-model [2] is represented by the refuge starting time, direction and walking speed. It is assumed that the refuge starting time is determined by the approach of the fire, while the number of refugees assumes a pseudo discrete normal distribution related to time (Fig. 2). It is also assumed that the crowd will take shelter at the closest refuge site, by making a detour to avoid shifting fire areas. The walking speed is expressed as a function of the crowd density (Fig. 3).

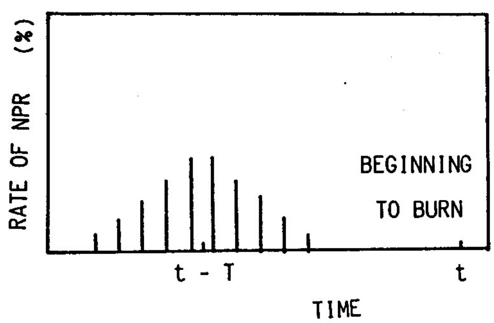

Fig. 2 People start to take refuge by the approach of fires and Number of People beginning to take Refuge (NPR) is given as a pseudo discrete normal distribution.

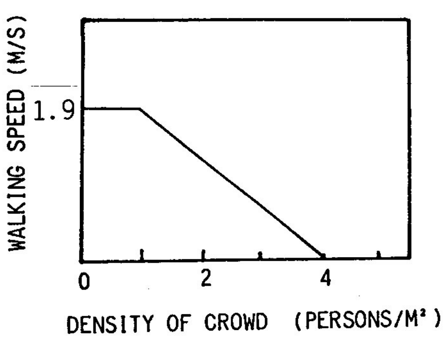

Fig. 3 Walking speed of the crowd is given as a function of its density.

The output information resulting from the above simulation includes the probability of each grid cell being burnt down, the number of fire fatalities in each cell at each time step, the number of those who reached an refuge site and those en route.

APPLICATION EXAMPLE "ICHIKAWA CITY"

The city under analysis, Ichikawa City, has an area of 56.4 km^2 and a population of approximately 430,000.

Input data
The entire area of Ichikawa City is divided into grid cells, 250 m per side, to each of which the width of roads and boundary conditions are given (Fig. 4). Each sell represents 250*250 m^2 area. The refuge sites are numbered in this figure. The number of those to be evacuated in each grid is determined by allotting the population for each cell based on the city demographic data.

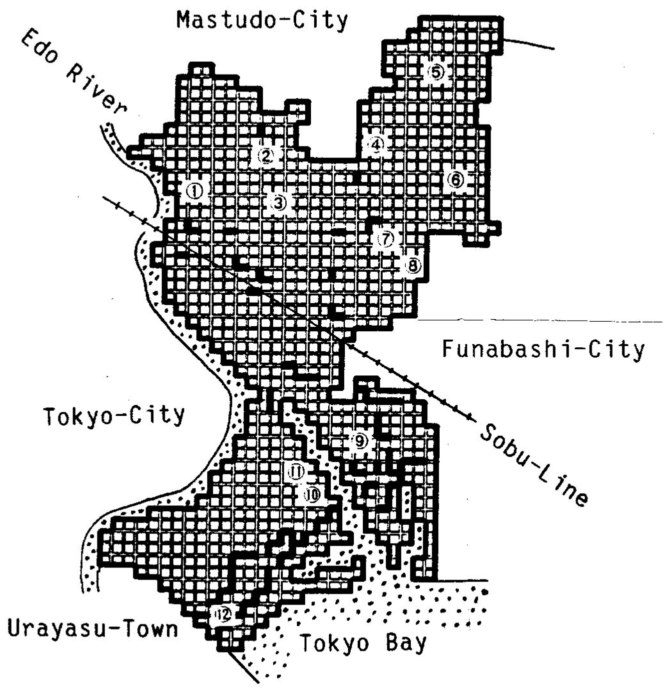

Fig. 4 Study area

It is assumed that fire breaks out at 83 points in a northern wind with a velocity of 3 m/s. The fire outbreak probability values at all grid point is calculated on the assumption that the index to fire hazard is proportional to the population. Urban data including the building type and building density status, which are parameters to define the fire spread behavior of each cell, is calculated based on the city tax records.

Refuge behavior is based on that of people at the time of the 1923 Great Kanto Earthquake. This means that the residents of each grid cell are assumed to begin evacuating when fire approaches as close as 107 to 127 m. Given that the refuge sites consist of 12 vacant lots each 20 ha and larger situated within and surrounding the city, all residents are assumed to proceed toward one of these sites.

One hundred fire patterns with random fire outbreak points are prepared based on the data obtained from the outbreak-of-fire sub-model and the spread-of-fire sub-model, while furthermore the refuge status of each fire pattern is calculated. The state of fire propagation is determined every minute, while the movement of the refugees as a crowd is calculated every 125 seconds for ten hours following the earthquake.

Fire hazard mapping
The probability of destruction by fire is determined for each grid cell based on the 100 fire patterns (Fig. 5).

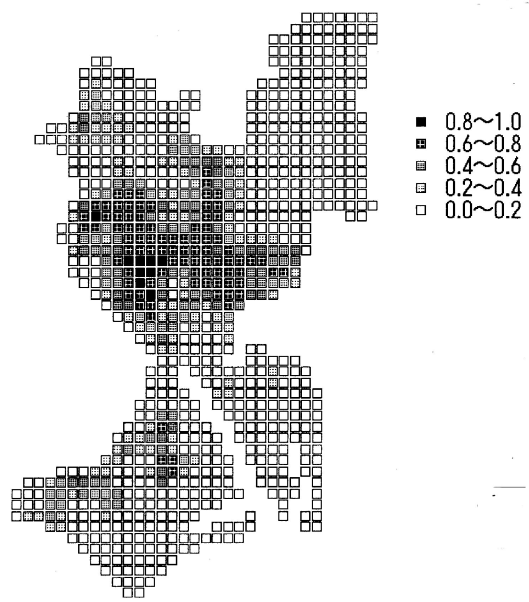

Fig. 5 Probabilities of destruction by fire in 10 hours are calculated from 100 fire spread patterns.

The central area of Ichikawa City along the Sobu railway line, which has been developed from the old days as a residential suburb of Tokyo, is densely populated and has a relatively large number of wooden structures. Figure 5 also indicates relatively high probability values for fire damage in this district. On the other hand, low damage probability values are indicated in the southern district, which is surrounded by rivers and the sea, despite the high probability of fire outbreak due to a dense population similar to the foregoing. This is because there are numerous reinforced concrete housing complexes in this district, which prevent fire from spreading.

Crowd evacuation status
Figure 6 shows the status of refuge sites based on one of the fire patterns. It indicates that the number of refugees is greatest in site No. 3, followed by Nos. 1, 11, 12, 7 and 9 in the descending order. At site No. 3, which is located in a rather densely populated area and close to where the initial fire destruction occurs, the rate of increase in the number of refugees begins to soar at about 1 hour after the earthquake. Ten hours later this number grows to approximately 100,000. This suggests that it is necessary to examine fire fighting and refugee security measures regarding the refuge routes leading to this site, while giving priority over other sites.

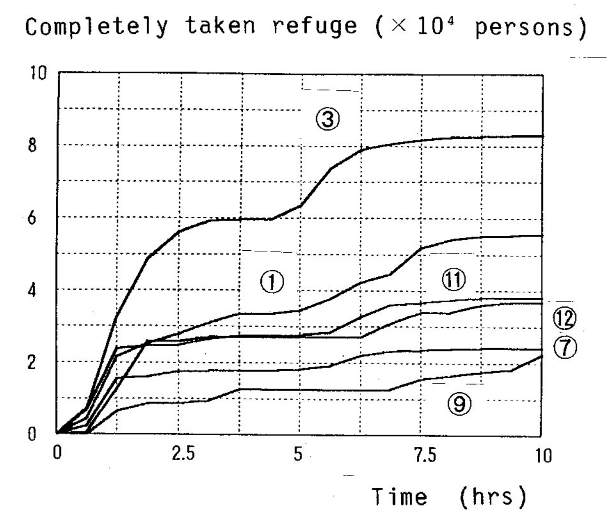

Fig. 6 Refugees in refuge sites increase with the passage of time.

Figure 7 shows the refuge status and the anticipated ratio of fire destruction based on all the fire patterns. It reveals that the number of refugees en route reaches as high as 30% of all residents 1 hour after the earthquake, suggesting that this particular time zone requires the strictest vigilance concerning refugee's security. Changes in the number of refugees depend primarily on the number of fire outbreak points, while being scarcely affected by the differences in the fire patterns.

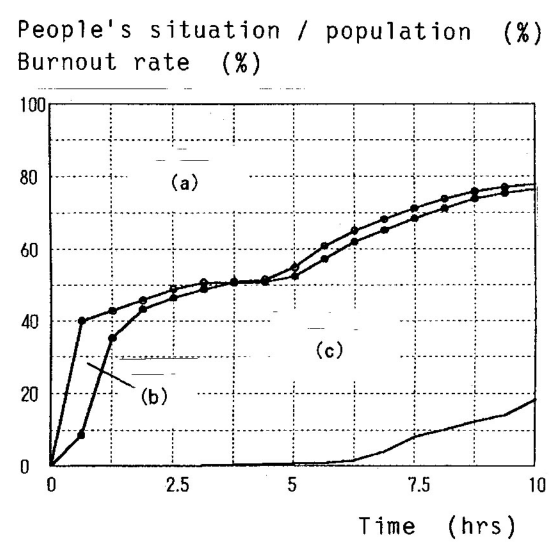

Fig. 7 All persons are divided into three groups, which are (a) do not taken refuge yet, (b) in the process of taking refuge & the fatalities and (c) have completely taken refuge. Destruction rate by fire is shown below right.

Estimation of fire fatalities

In this section, the number of fatalities is estimated for each of the 100 fire patterns. This represents the number of residents who die after being surrounded by multiple fires, which largely occurs after seven hours and more following an earthquake. The minimum and maximum numbers of estimated fatalities by the 100 patterns are 234 and 7,027, respectively, with the average being 1,782.

The fire pattern which produces the least number of fatalities (Fig. 8(upper)) is that in which the fire spreads from the city center outward to its surrounding area, meaning that this allows the residents to easily reach a refuge site. On the contrary, in the case of the fire pattern which produces the largest number of fatalities (Fig. 8(lower)), it is speculated that a considerable number of people die in the areas where they become surrounded and trapped by a large-scale fire (shown as A and B in the figure). In consideration of the fact that the ratios of areas burnt down by these two fire patterns are similar at around 20% after 10 hours, fire outbreak/propagation patterns are found to produce a substantial effect on the number of fatalities.

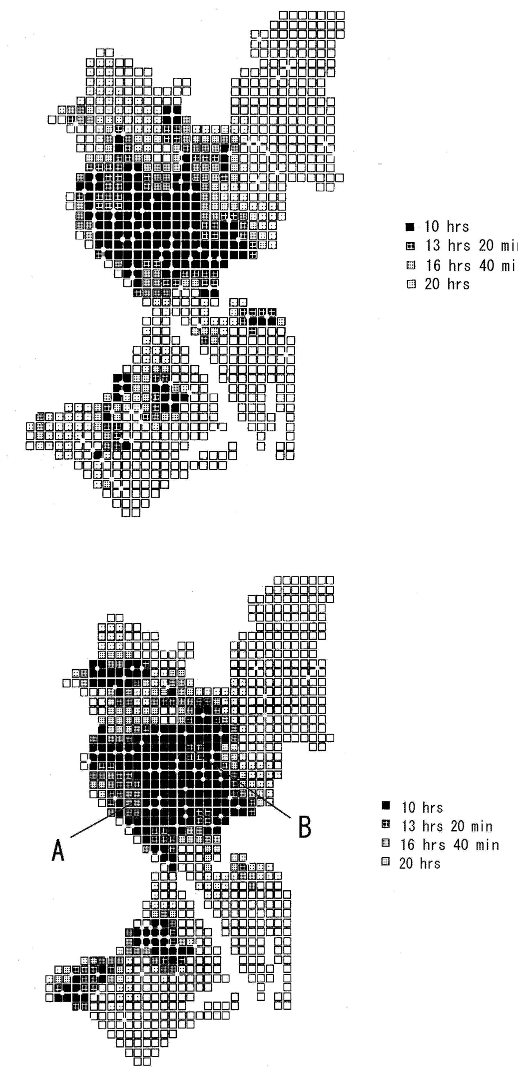

Fig. 8 Differences in the number of the fatalities are attributed to fire spreading pattern, which is affected by the distribution of fire breakouts, for example (upper) minimum fatalities and (lower) maximum.

Considering the time when fatalities occur and the refuge status, it is suggested that a refuge directive should generally be given to the residents 3 to 5 hours following an earthquake at the latest, in order to prevent fire fatalities.

CONCLUSIONS

The author proposed this simulation technique concerning fire and refuge following an earthquake, while introducing its application to an actual city area, thereby demonstrating that it can provide valuable information for the formulation of fire measures as well as refuge plans. The characteristics of this technique are as follows:

This method, as it stochastically treats the phenomenon of fire outbreak, allows estimation of the anticipated fire damage and human casualties during refuge.

The possibility of casualties caused by a crowd thrown into panic at and around bridges and the entrances of refuge sites is of concern during refuge after an earthquake. This technique makes it possible to obtain information regarding time-related changes in the density of the crowd at these critical points.

Through its assumption of a refuge status based on various fire patterns, the technique enables proactive consideration of countermeasures such as determination of the order of priority concerning fire fighting activities and security/guidance for refuge routes, in order to reduce casualties.

As the design of this technique is simple, it is easily applicable to emergency measures to be taken immediately following an earthquake.

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