EVACUATION BEHAVIOR IN CITY FIRE FOLLOWING EARTHQUAKE

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Abstract : In this study, we propose a model which describes evacuation behavior in a city fire following a strong earthquake by considering the effect of evacuees' familiarity / unfamiliarity with areas. Through some of the simulations in the model, we examine the layout of evacuation areas. As the result, it is shown that the largest number of people can evacuate in the case that all evacuation areas are placed on the center of the target city.

1 INTRODUCTION

1.1 Background and Objectives

Many studies on evacuation behavior in a city fire following a strong earthquake have been carried out (e.g., Itoigawa et al 1989). Most of these studies were based on the assumptions that everybody can take an appropriate route and evacuate to the nearest evacuation area. From the following two reasons, however, those assumptions are hardly accepted in the case that people evacuate in an unfamiliar area. The first reason is that it seems to take more time to move in an unfamiliar area by losing their way or taking roundabout route. The second reason is that people are likely to take familiar routes even if more suitable and short routes may exist, as shown in Murosaki and Yamada (1980). Hence, in this study, we construct a model which describes evacuation behavior in a city fire following an earthquake by considering of the effect of their familiarity with areas, and examine the proper layout of evacuation areas through simulations.

In the previous study, Aoki et al (1992) showed that the information boards on main evacuation routes could bring smooth evacuation. In addition, the effectiveness of pre-learning and guide-information was reported (Kaji 1989, Aoki et al 1992, Kumagai 1992, Kakei et al 2000). However, evacuees' familiarity / unfamiliarity with areas was not discussed in the previous researches.

1.2 Simulation Model

It is necessary to integrate the situation of fire spreading and behavior of evacuation, when we estimate human injuries caused by considering the phenomenon in which evacuees are surrounded and killed in the flames. It is, however, too difficult to treat the situation of fire spreading and behavior of evacuation simultaneously using the real complex road networks of cities.

From the viewpoint of practical availability and effectiveness, a grid based model was proposed (Okada et al 1979). In this model, on one hand each area is represented by a grid, and the behavior of evacuation is expressed by the number of person who move across the boundary between two adjacent grids, and all the evacuation starts directly after the earthquake. The amount of movement per unit time is determined by the total road width on a grid line. On the other hand the original point of a fire is represented on the intersection of two grid lines, and the state of fire spreading is represented on grid lines. The accuracy of these model is limited since the situation of inside of grids is simplified, while it is still useful for looking at the situation in perspective.

In this study, the Okada's model is modified by describing the evacuation behavior more accurately. In the following section, the outline of model is described. The details of this model can be found in Okada et al (1979) and Aoki et al (1992).

2 FIRE-SPREAD MODEL

Spreading of fire is considered as a kind of stochastic processes. Therefore, Monte Carlo method is appropriate for simulating fire-spreading of each building. In respect of a grid based model, however, it is not always effective to use an accurate stochastic model like the Monte Carlo method. Hence, in this study, we adapt a compact and non-stochastic model based on Hamada's formulation which was used in Okada et al (1979). In this model, we assume that the specific number of fires break out at random place after a strong earthquake, and spread at the speed V represented by equation (1):

$$V = C_w \times C_e \times K \times V_{wood}, \tag{1}$$

where C_w and C_e are the coefficient of wind and the coefficient of extinguishing respectively. In addition, K is the coefficient of prevention of surrounding buildings and V_{wood} is the fire spread speed in pure wooden urban district. The value of K is calculated as follows:

$$K = \big\{(a+b)(1-c)\big\} \div \big\{a + \frac{b}{0.6}\big\}, \tag{2}$$

where the parameters a, b and c respectively represent the ratio of pure-wooden buildings, fire-prevention building and fire-resistant building. The above parameter C_w, C_e and V_{wood} are set up as the average state of city as follows:

$$C_w = 1.0, \;\; C_e = 0.8, \;\; V_{wood} = 2.3m/min.$$

3 EVACUATION MODEL

3.1 Daily Life Area (DLA)

The area where people usually move on foot is seemed to be restricted, and people seldom move to the outside of this area. In this study, this area is called Daily-Life-Area (DLA) and the effect of this area on the evacuation behavior is discussed.

DLA seems to be similar to the area surrounding the house and nearest railroad station in Tokyo or other Japanese cities. Hence, we compute DLA in the following procedures. Firstly, we draw the straight line which connects a evacuee's house and the center of district which includes a railroad station. If evacuees at Area(x_0, y_0) are in their DLA, we express $DLA(x_0, y_0) = 1$, and otherwise $DLA(x_0, y_0) = 0$. In case evacuees in an area come from two or more areas, the coordinates(x_0, y_0) of Area(x_0, y_0) is obtained from the average coordinates weighted by the number of evacuees.

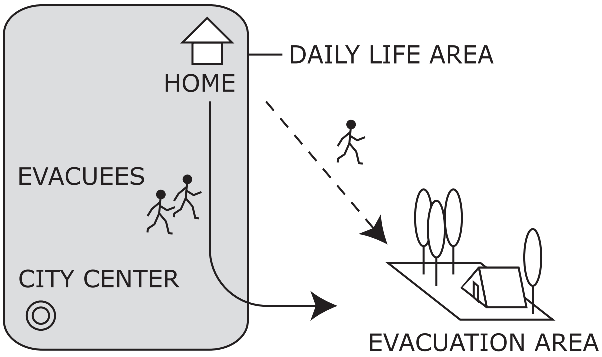

Figure 1: Daily-Life-Area

3.2 Effects of Daily Life Area in Evacuation Behavior

Evacuees staying at outside of DLA are likely to lose their way or take roundabout route, as compared with evacuees in DLA. That is, the evacuation speed at outside of DLA is expected to be less than that at inside of DLA. Therefore, we estimate the time to move across a grid line for each evacuee, denoted by T, as follows:

$$T(x, y) = \frac{(1 - \alpha DLA(x, y)) \times E(x, y)}{\sum_w C_f \times R_p(x, y, \omega)}. \tag{3}$$

In equation (3), α expresses the effect of DLA. $\alpha = 0$ shows the case that the effect of DLA is negligible, and $\alpha = 1.0$ shows the case that the effect of DLA is critical. In the following case study, the value of α is changed at intervals of 0.2 from 0.0 to 0.6. In addition, $E(x, y)$ is the number of evacuees, $R_p(x, y, \omega)$ is total width of passable road to each direction and C_f is the coefficient of fluidity of crowded people. The value of above parameter C_f is assumed to be low, i.e., $C_f = 1.0\ person/m \cdot sec$, since old people and children are included in evacuees.

3.3 Evacuation Route Selection

In this model, evacuees in the same area are treated as one group and move together. When a group of evacuees on each grid decides where to go next, the following procedures are used. Firstly the average time to pass through each areas is estimated by equation (3). The time to pass areas in outside of DLA are excessively estimated according to the effect of DLA (α). Secondly the shortest time to reach to each evacuation area is searched, and the route is recorded. Finally the evacuation area, where the time for evacuation is shortest and the capacity is large enough, is selected. Thus, the grid which the group of evacuees moves to is determined. Note that they don't move toward the truly nearest evacuation area.

After the above procedures, the number of evacuees who move to the next grid is determined by the total road width on grid line as $M(x, y, \omega)$ by following equation (4):

$$M(x, y, \omega) = E(x, y) \times \frac{R(x, y, \omega) \cdot C_v \cdot C_f}{\sum_w R(x, y, \omega) \cdot C_v \cdot C_f}, \tag{4}$$

where $E(x, y)$ is the number of evacuees, $R(x, y, \omega)$ is total width of passable road in the each direction, C_v and C_f are the coefficient of effective road width and the coefficient of fluidity of crowded people respectively. The value of C_v is assumed to be 0.4 because many barricades on evacuation routes such as cars and various obstructions disturb their evacuation. Evacuees who reach to evacuation area are added to the number of successful evacuees. Evacuees who can't move any directions in surrounding fire are regarded as death toll.

4 CASE STUDY

The space of target city is composed of the grid data of 20×20 cells, and the size of a grid represents 500m×500m. In this study, we compare the following 4 layouts of evacuation areas (see figure 2). All evacuation areas of type-A are distributed on the perimeter zone, meanwhile all evacuation areas of type-D are distributed on the central zone.

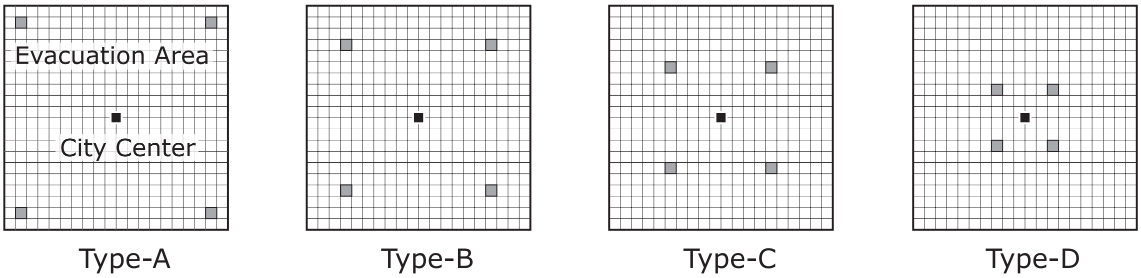

Figure 2: Layout of evacuation area

The process of evacuation is visualized in figure 3. The number of evacuees in each area is represented by the color of area. The number of evacuees who move to neighboring area is represented by the length of arrows on each grid line. Each original point of a fire is represented at one of the intersections, and fire-spread is represented on grid line.

Figure 4 shows the process of evacuation and fire-spread of each layout. Quite different movement of evacuees is observed for each layout. Figure 5 shows the relationship between the speed of evacuation and the effect of DLA(α). The ordinate is total number of evacuees who succeed in evacuation in 10 hours. It is obvious that the largest number of people can evacuate in the case of type-D. This means that if the effect of DLA is not negligible, type-D is the best among these 4 layouts.

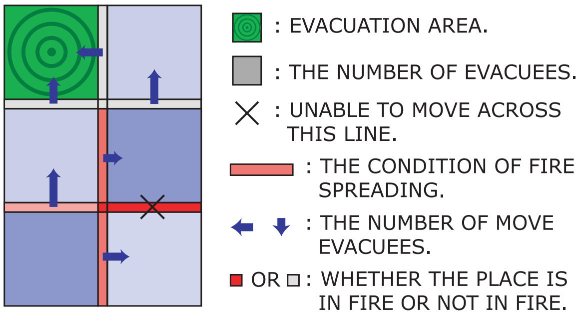

Figure 3: Visualization of evacuation process

In order to understand the detail of this result, the process of evacuation of each layout is examined. Figure 6 shows the changes of evacuation speed according to lapsed time after earthquake. The ordinate is the number of evacuees who succeeded in evacuation in 1 hour. It is shown that type-A is superior layout in 2 hours after earthquake, and type-B and type-C are superior layouts in the next 2 hours. However, type-D becomes the most superior layout after 4 hours.

5 Conclusion

The proper layout of evacuation areas are examined by considering the difference in evacuation behavior caused by evacuees' familiarity / unfamiliarity with areas. As the result of 4 layouts of evacuation areas, the largest number of people can evacuate in the case that evacuation areas are placed on the center of the city.

In Japan, evacuation areas are often located in public facilities such as large parks in the suburbs. However, according to our results of some simulations, evacuation areas should be located at the center of city, although further research is needed.

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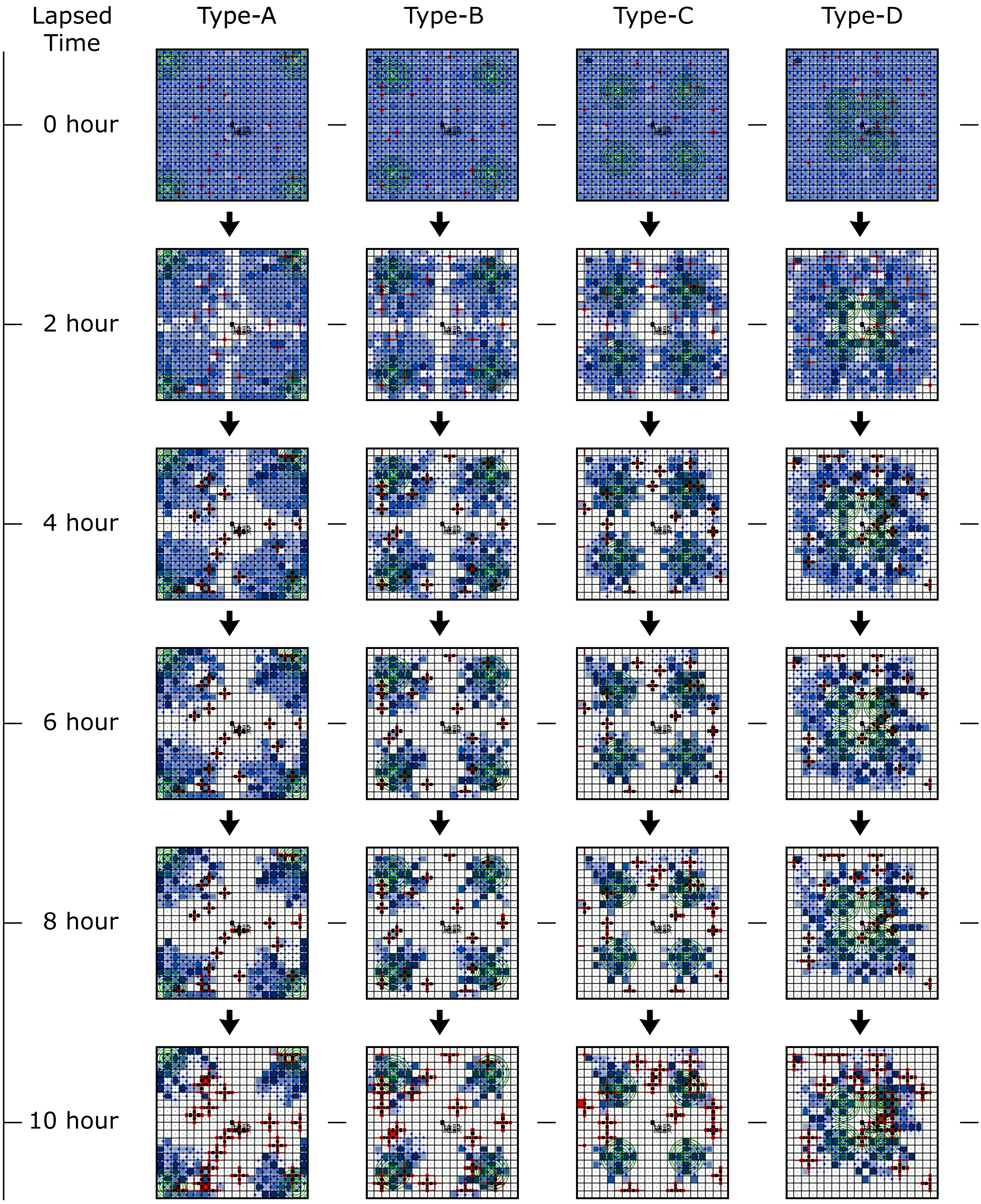

Figure 4: The process of evacuation and fire-spread (α=0.2)

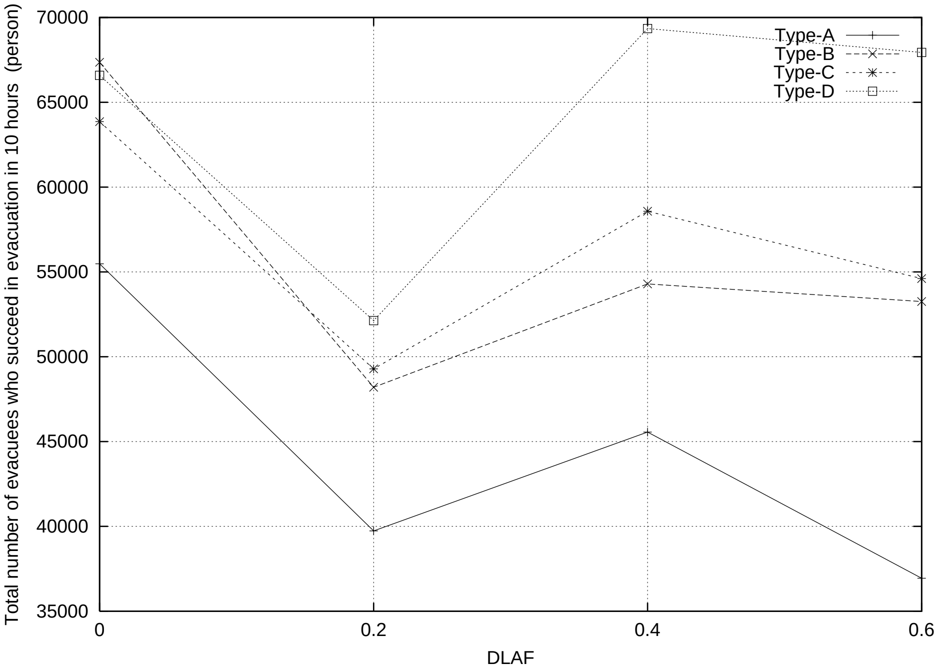

Figure 5: Total number of evacuees who succeed in evacuation in 10 hours

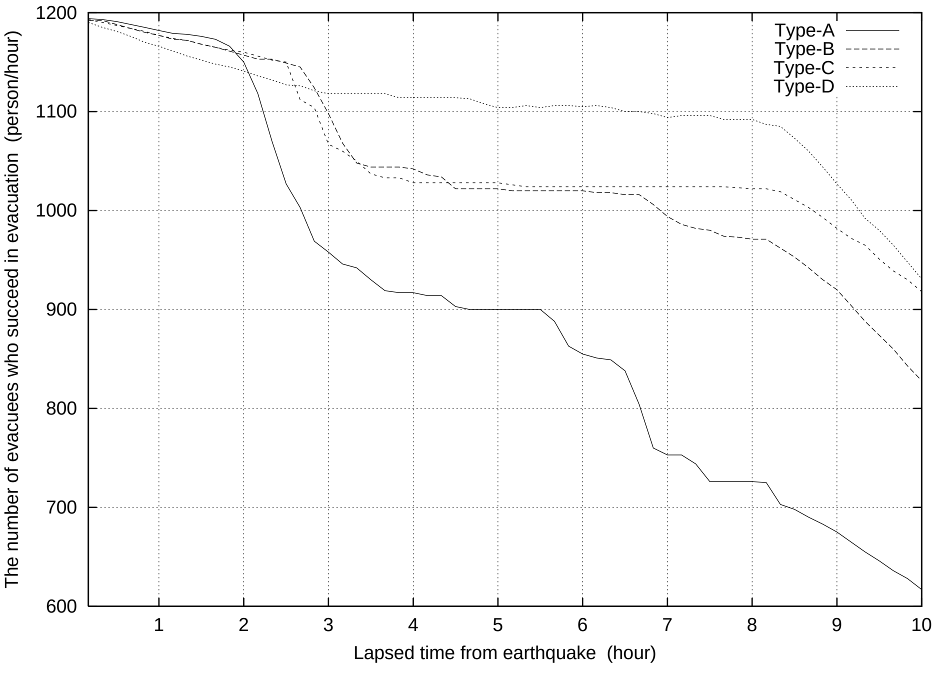

Figure 6: The changes of evacuation speed according to lapsed time after earthquake (α=0.2)