A STUDY ON URBAN FIRE SPREAD CONSIDERING OPENINGS

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ABSTRACT

The coefficient of fire-spread velocity, which depends only on the construction types in a city, has been used in studies of fire spread without considering the opening conditions of the buildings. The coefficient is unrelated to openings. However, most actual fires spread mainly through openings between one building and another. Therefore, existing studies are based only on rough estimates using a macro analysis, and more precise research is needed. This paper presents a simulation of fire spread that depends on the velocity of the fire as it spreads between adjoining buildings, considering openings as well as construction types. This simulation is more detailed and more realistic than those in previous studies. Also presented is a simulation of fire spread depending on the above-mentioned coefficient to allow a comparison between the two types of simulation. It is concluded that the simulation pertaining to openings is very close to the conditions in an actual fire and also that the distribution of construction types has a great influence on the fire spread, especially when many of the relevant buildings are wooden.

Keywords: Coefficient of fire-spread velocity, fire-spread velocity between adjoining buildings, fire-spread simulation, construction type, opening.

INTRODUCTION

Japanese researchers have made great efforts to calculate accurately the velocity at which fires spread. However, all existing studies on this velocity are based on macro-estimates. This is because the main factor in calculating velocity is the coefficient obtained by computing the ratio of construction types: wooden, fire preventive wooden, and fireproof. This is called the coefficient of fire spread velocity, or CFSV.

It is very clear that micro-estimated fire spread simulation is needed in order to calculate the likely spread of a real fire. A large earthquake is usually followed by a large fire, which can be as dangerous to human life as the collapse of buildings. In addition, it is very important to evaluate how well a city can resist fire spread without fire fighting: after a major earthquake. Fire fighters are not as effective as usual or may even be unable to work because the infrastructure has collapsed.

When engaging in a micro-estimated fire spread simulation, openings are the key factor. It is true that fire can easily reach any spot on the wall of a wooden building, but in a wooden building that is fireproofed, or an entirely fireproof one, the fire will usually move first to the openings and penetrate them. At the same time, the fire will spout from the openings of those buildings in which it originated.

In this paper, the velocity at which a fire spreads between two adjoining buildings is established, and how this process pertains to openings as well as to construction types is explored. This calculation of velocity is more detailed and more accurate than the fire-spread velocity calculated by using the coefficient. That is because this calculation focuses not on a whole city but on two adjoining buildings. A macro-evaluated simulation of fire spread is also presented using the traditional coefficient in order to compare the two different types of simulations.

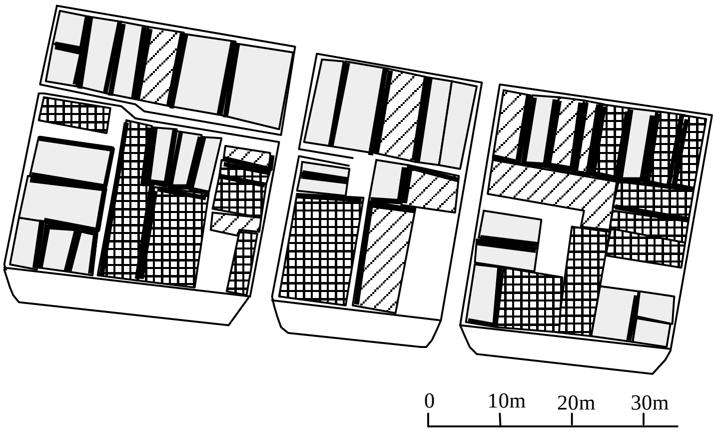
Furthermore, fire spread is simulated in two different areas to allow a comparison. The ratios of construction types of the two areas were very similar. However, the distributions of the three construction types across the two areas are very different. For that reason, consideration is also given to the distribution of construction types. It is concluded that it is possible to construct many wooden buildings as long as they are dispersed among buildings that are either fire preventive wooden or fireproof.

The areas chosen for the fire spread simulation

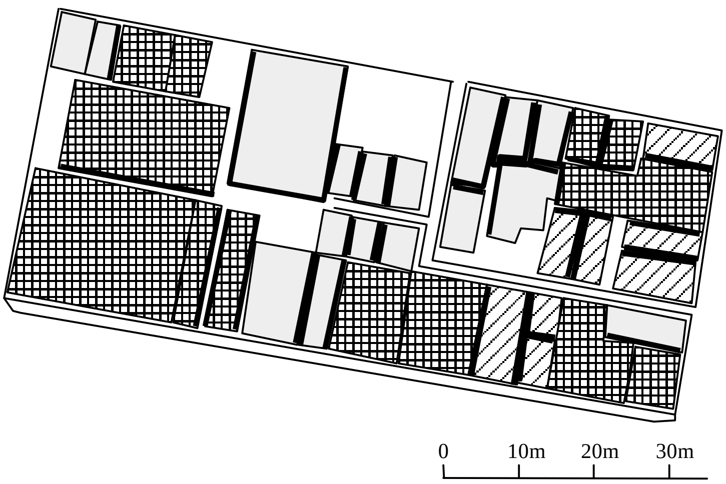
Two areas in Taito city, Tokyo, both of which include more wooden buildings than ordinary areas in Tokyo, were selected for the fire spread simulation. They are shown in Figure 1. The ratios of construction types in the two areas are similar, as shown in Table 1, but the two types are distributed differently. Therefore, the importance of the distribution will be evaluated by examining the results of the two simulations.

Table 1: Percentages of construction types in the two areas.

	Wooden	Fire Preventive Wooden	Fireproof
Torigoe	44.40%	20.60%	35.00%
Kojima	34.30%	12.80%	52.90%



1-5,6,7 Torigoe, Taito



1-4 Kojima, Taito

Plain color : wooden	bold line : a wall without openings
Slant lines : fire preventive wooden	light line: a wall with openings
Grids : fireproof	

Figure 1: The areas for fire spread simulation.

The simulation using the coefficient of fire spread velocity

The first step was to calculate the speed at which fire spreads and then the areas of the relevant buildings.

Calculating the velocity of fire-spread

The fire-spread velocity *V*(m/min) is proportional to the coefficient *n*[1]. That is:

$$V = n \times 0.48 \tag{1}$$

0.48 is determined as the speed at which fire spreads between the two wooden buildings[1].

The coefficient of fire-spread velocity is calculated using the ratios of the three construction types as follows:

$$n = \frac{(a'+b')}{a'+\frac{b'}{0.6}}(1-c') \tag{2}$$

a': the ratio of wooden buildings to all buildings

b': the ratio of fire preventive wooden buildings to all buildings

c': the ratio of fireproof buildings to all buildings

The fire-spread velocities of the two areas were calculated using Equations 1 and 2. According to Table 1, in the case of 1-5,6,7 Torigoe, Taito, *a'*=0.444, *b'*=0.206, and *c'*=0.350. This is why *n* is computed at 0.537 in the second equation. Next, *V* is computed to be 0.26 m/min by the first equation.

Finally, using the values in Table 1, in 1-4 Kojima, Taito, *a'*=0.343, *b'*=0.128, *c'*=0.529. That is why *n* is 0.399 and *V* is 0.19 m/min.

The results indicate that the fire front will move concentrically from the point where the fire starts, at the speed above. In addition, fireproof buildings are assumed to be equivalent to vacant space, without any buildings.

Calculating the area of the buildings to which the fire spreads

In the case of Torigoe, three patterns of fire spread were simulated, assuming that a fire will start at a wooden building in the eastern, the middle, and the western block. Each simulation has only one fire starting point, and has nothing to do with other simulations. Then, in the case of Kojima, the three patterns of fire spread were simulated in exactly the same way. In Figure 2, as an example, the results of the two simulations of the cases where the fire starts at a wooden building in the eastern block are presented.

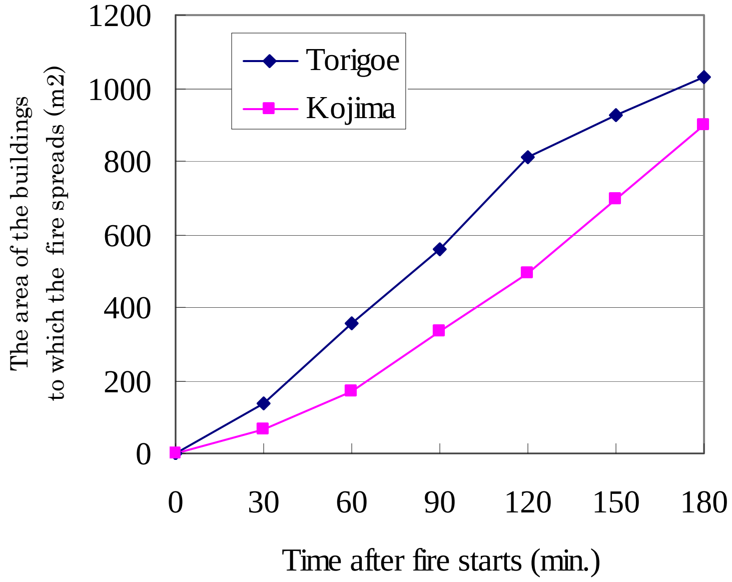


Figure 2: Simulation of fire-spread using CFSV, with the fire starting in a wooden building in the eastern block.

Comparing the two lines in Figure 2, it can be seen that in the first 120 min, the fire in Torigoe increases more dramatically than the one in Kojima. This is simply because the velocity of the Torigoe fire (computed in the previous section) is higher than that of the Kojima fire. On the other hand, after 120 min, the Torigoe fire does not increase greatly, while the one in Kojima continues to grow. This is because of the assumption that the fire front will move concentrically from the point where the fire starts. In the case of Torigoe, after 120 min, the fire front has already moved beyond the edge of the area on the map, so the fire appears not to increase much after 120 min.

The situations described above can be inferred from Figure 2. However, the point where the fire starts in Torigoe faces fire-preventive wooden buildings in three directions, while the equivalent point in Kojima faces wooden ones in two directions. For this reason, especially in the early stage, the velocity of the Kojima fire should be higher than that of the Torigoe fire. But the simulation above gives the opposite result. This reveals the limitation of the simulation using the coefficient, which is validated in a macro-evaluation. Micro-evaluation is also needed to make a more precise analysis. This can only be accomplished by conducting a simulation that considers openings.

The simulation considering openings

Firstly, the velocity of a fire between two buildings was calculated, then the simulation was conducted, and comparisons were made between the various cases.

The velocity of fire-spread between two adjoining buildings

Table 2 shows the fire-spread velocities used in this section; the four values in the gray-shaded boxes were published by the Tokyo Fire Department[2]. The values in the remaining white-colored boxes were chosen provisionally for this simulation. The distance between the two centers of the adjoining buildings, divided by the relevant velocity shown in Table 2, is the time the fire takes to spread to the adjoining building.

Table 2: Fire-spread velocities between two adjoining buildings (m/min).

	A building to which the fire spreads	Wooden		Fire preventive wooden		Fireproof	
A building where the fire starts	A wall with/without openings	With	Without	With	Without	With	Without
Wooden	With	0.48	0.48	0.41	0.27	0.12	-
	Without	0.48	0.48	0.27	0.21	0.08	-
Fire preventive wooden	With	0.41	0.41	0.4	0.26	0.1	-
	Without	0.41	0.41	0.26	0.2	0.07	-
Fireproof	With	-	-	-	-	-	-
	Without	-	-	-	-	-	-

Moreover, when the fire spreads to a wooden building, the velocity is constant and independent of openings. When the fire spreads to a fire-preventive wooden building, its velocity is slower if the wall has no openings. The fire cannot start in a fireproof building, and it can spread to a fireproof building only when the wall includes openings.

For the sake of comparison, a simulation was also conducted by not considering openings, and using only the four values in the gray-shaded boxes. In that simulation, all the walls were assumed to include openings.

The fire-spread simulation

In the case of Torigoe, six simulations were conducted. Three of them considered openings, with the fire starting in a wooden building in the eastern block, in the middle block, and in the western block. The other three simulations did not consider openings. Likewise, six simulations were conducted in the case of Kojima. This makes a total of twelve simulations.

One example of the fire-spread simulation is shown in Figure 3. This simulation of Torigoe considers openings, and the fire starts in a wooden building in the eastern block. The time when a building catches on fire, is expressed by tile patterns in 30-min intervals. The time limit is 180 min, and the fire-spread after 180 min is not considered.

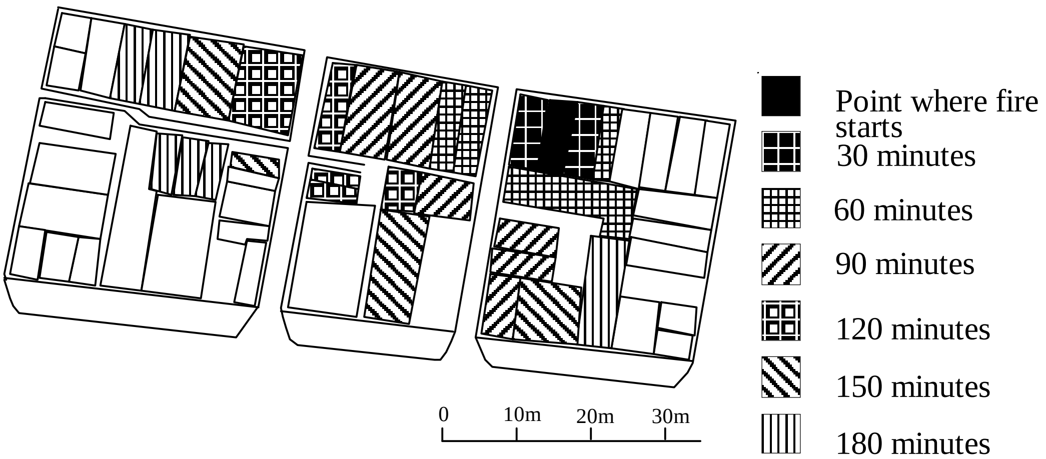


Figure 3: The fire-spread simulation of Torigoe considering openings. The fire starts in a wooden building in the eastern block.

Comparison of the simulations

The results are now compared of the simulations: those with and without openings, in Torigoe and Kojima, and in Figures 2 and 5.

Comparing the simulations considering and not considering openings

Figure 4 shows the results of the two fire-spread simulations for Torigoe. Only one considers openings. In the both cases, the fire starts in a wooden building in the eastern block.

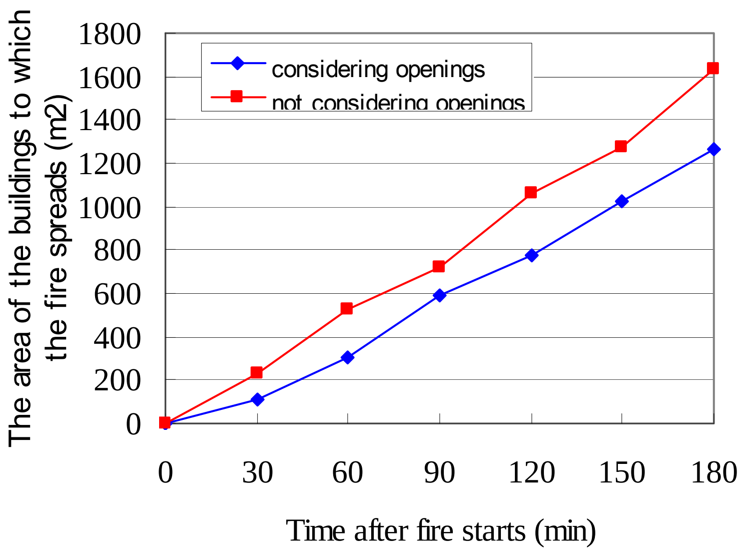


Figure 4: Fire-spread simulations for Torigoe.

As shown in Figure 4, in the simulation not considering openings, the fire increases more quickly than in the simulation with openings. For this reason, the simulation not considering openings produces a more dangerous result than the real thing, and leads people to be more careful than necessary. In short, accurate results cannot be obtained from a fire-spread simulation if openings are not considered. Thus, the more accurate simulation, which considers openings, will definitely be needed.

Comparing Torigoe with Kojima

The results of the simulations for Torigoe and Kojima are shown in Figure 5. Both consider openings, and the fire starts in a wooden building in the eastern block.

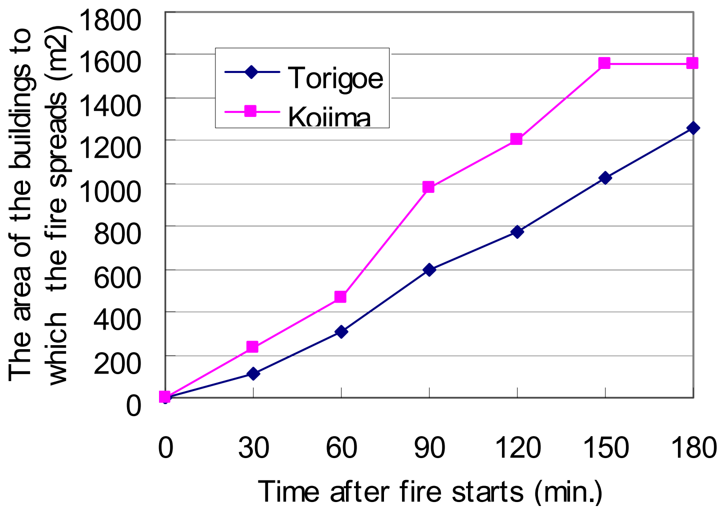


Figure 5: The fire spread simulations of Torigoe and Kojima considering openings.

Figure 5 shows the influence that the distribution of the three construction types has on the fire-spread. The distribution is shown in Figure 1. The fires in Torigoe and Kojima are not very different from each other in the first 60 min, but between 60 and 150 min, the Kojima fire increases far more quickly than the one in Torigoe. This is because the middle block of Kojima is full of wooden buildings and does not include the other two types of buildings that are fire preventive, while the equivalent area in Torigoe includes all three types of buildings. On the other hand, the eastern blocks of both areas include all three building types. Accordingly, the fire front does not advance very quickly in the eastern blocks of either area, while it advances far more quickly in the middle block of Kojima than in that of Torigoe. Then, after 150 min, Torigoe's fire continues to grow, while the one in Kojima remains constant. This is because even the western block of Torigoe includes all three building types, while that in Kojima is full of fireproof ones.

In summary, the comparison above shows that the two areas are not very different until 60 min has passed. Then, from 60 to 150 min, it is far safer in Torigoe, and at 180 min, the two are almost the same again. Fire fighting conditions are not considered in this evaluation, making it very close to the actual situation in the case of an earthquake.

As shown in Figure 2, in the simulations that consider the coefficient of fire-spread velocity, a fire in Torigoe increases more quickly than one in Kojima, and both occupy less than 1200 m^2 at 180 minutes. On the other hand, as shown in Figure 5, in the simulations that consider openings, a fire in Kojima increases faster than one in Torigoe, and both have grown to more than 1200 m^2 at 180 minutes.

The results of the two types of simulations are quite different, and the simulation that uses the coefficient is vague and rough, while the simulation that considers openings is very detailed and close to the spread of a real fire. In order to understand how an actual large fire may spread after a major earthquake, it is crucial to improve the accuracy of simulations. The authors believe this chapter is an important first step.

CONCLUSIONS

Simulations that consider openings provide more accurate results than the traditional simulations that rely on macro-evaluation. The distribution of the three construction types has a great influence on the speed at which fires spread, and wooden buildings contribute to the spread of fires only when they are clustered close together. It is reasonable for cities to include many wooden buildings as long as they are dispersed among other buildings that are fire preventive wooden or fireproof. Future simulations should consider related factors such as: the location of openings on a wall; their shape and area; types of glass; collapse of roofs; and wind velocity. Such simulations should also be more detailed and more accurate.

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