AN INVESTIGATION ON THE DISTRIBUTION OF FIRE BRANDS AND SPOT FIRES DUE TO A HOTEL FIRE

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ABSTRACT

A hotel fire occurred in Shirahama, Wakayama prefecture on November 17th 1998. This building fire was one of the widest burning area of building fires in Japan. During this fire, there was high wind velocity at about 7m/sec. At the same time, there was a lot of number of fire brands. We surveyed the distribution of fire brands and spot fires due to this fire by exploration and questionnaire. As a consequence, it was found that through exploration and questionnaire that there is a relation between the distribution of fire brands and the size of fire brands etc.

Keywords : Fire Brand, Spot Fire, Exploration, Survey on questionnaire, Hotel Fire

1. INTRODUCTION

When a fire spreads from building to building, part of the cinders of building materials and storage furniture is carried up in the thermal up-draft in the form of fire brands and is scattered about from the fire building. Depending on the weather conditions, these fire brands may fly over a distance of several kilometers. Some investigation results concerning the distribution of spot fires caused by such flying brands have been reported [1]. Many of these reports deal with the relationships of the range of fire brand distribution and spot fires with weather conditions such as wind velocity and the topography of the area of origin [2]. However, although it is believed that the range of fire brand distribution and spot fires are somehow interrelated to such factors as the size of the seat of fire and the quantity of fire brands generated, few investigations taking this into consideration have been conducted thus far.

On November 17, 1998, a fire broke out at a

hotel (Tenzankaku) in the Shirahama hot spring resort (Shirahama-cho, Nishimuro-gun, Wakayama-ken), and fire brands were scattered over a wide area. In the area surrounding the hotel from which the fire originated, a strong wind was blowing from the sea at the time of the fire. This wind contributed to the spread of the hotel fire, but it also made the area of destruction very large for a single building, and a large quantity of fire brands were scattered around. This paper reports on the results of an investigation and a questionnaire survey conducted by the authors to characterize a series of processes from fire brand generation to ignition and determine the extent of spot-fire damage.

2. OUTLINE OF THE FIRE [3,4]

As shown in Figure 1, the hotel building destroyed by the fire was a complex structure consisting of reinforced concrete, steel, and wooden substructures and had a total floor area of 12,589

m². Because a strong wind was blowing from the sea to the south-southeast when the fire occurred and because the (estimated) point of origin was located on the windward side of the hotel, the fire spread in the leeward direction, and the area of destruction reached about 12,000m² (still under investigation). While the wooden annex building was on fire, a large quantity of fire brands were produced. The time elapsed from the outbreak to the extinguishment of the fire was as follows:

- Outbreak of fire
: around 18:00 (still under investigation),
November 17, 1998
- Recognition of fire
: 18:38, November 17, 1998
- Extinguishment of fire
: 6:00, November 18, 1998

Figure 1. Site Plan

The weather conditions during the time between the outbreak and the extinguishment of the fire are summarized in Figure 2. As shown in Figure 2, wind velocities recorded at a nearby location (Shirahama Fire Department Headquarters; see Figure 3) were around 7m/s, and gale and high wave advisories had been issued by the Wakayama Local Meteorological Observatory. One newspaper reported a maximum wind velocity of about 18m/s. As shown in Photo 1, in the coastal area in which the fire building was located, various structures had been built on a terraced slope, and the topography had considerable rises and falls. This topography must have greatly affected wind directions and wind velocities in the area.

a) Wind velocity

b) Outside air temperature

c) Humidity

Figure 2. Weather conditions

Figure 3. Range of fire brand distribution

Photo 1. View around hotel where fire occurred

3. THE RANGE OF FIRE BRAND DISTRIBUTION AND DAMAGE CAUSED BY SPOT FIRES

As shown in Figure 2, fire brands were scattered about widely and caused spot fires partly because a strong (about 7m/s) wind was blowing when the fire occurred. This section presents investigation results concerning the distribution of fire brands and spot fires caused by flying brands.

3.1 Damage to adjacent buildings due to fire brands

This section reviews how fire brands flew from the burning hotel to nearby buildings. Many fire brands were observed on a one-meter-wide walkway between the hotel from which the fire originated and an adjacent hotel building (A-1) on the east side of the hotel. In particular, a walkway section in front of a wooden annex building of the hotel from which the fire originated was littered with fire brands of varied sizes. The exterior wall and the glass surfaces of glazed windows of the sanatorium (A-2) located to the east of the annex building were found to be covered with soot, and a considerable quantity of fire brands were found on the yard of the sanatorium. As the sanatorium was located on the leeward side of the building of origin at the time of the fire, large quantities of smoke and fire brands have probably been blown against the wall and the windows. There was a wooden dwelling (A-3) on the south side of the hotel, and a large quantity of powdery fire brands were found on the wall of the house facing the area of origin. Fire brands were also found on a 4-meter wide road between the houses and stores (A-4) on the west side of the hotel and the area of the origin, and a witness reported that fire brands several tens of centimeters in diameter were flying toward the houses and stores (A-4). These investigation results indicated that fire brands flew toward adjacent buildings on all sides of the building of origin except the north. Effective fire operations by firefighters and local residents, however, prevented major damage due to these

fire brands.

3.2 Range of fire brand distribution

Figure 3 shows the range of fire brand distribution, along with spot fire locations. As shown in Figure 3, a strong wind was blowing mainly to the south-southeast at the time of the fire, and fire brands were scattered about widely, mainly to the leeward direction. According to Figure 3, the maximum distance (projected horizontal distance) from the scene of a fire where flying brands had been spotted was about 850m, and the difference in elevation was about 100m. The maximum width of a fire brand distribution zone was about 500m, and the angle of distribution was around 85 degrees (from the windward end of the scene of the fire). The wind direction shown in Figure 2 indicates that a disproportionately large quantity of fire brands were distributed on the east side of the hotel from which the fire originated. This is due to the topography of the area, and it is possible that the wind was not necessarily blowing in the direction shown in Figure 2. According to one witness, fire brands and their cinders were falling like "powdery snow" over a distance of about 200m on the leeward side of the building of origin.

3.3 Spot fires caused by fire brands

The field investigation confirmed that plantings at a sanatorium (B-1) and at a dwelling (B-2) about 250m from the building of origin caught fire (Figure 3 and Photo 1). About 100m² of forest facing the sanatorium and the dwelling burned also caught fire. A stand of trees at a hotel (B-4) about 450m to the southeast of the building of origin also caught fire, but it was also extinguished by firefighters. When the fire occurred, a strong wind was blowing intermittently against this hotel. The wind was so strong that a person walking on a hotel balcony against the wind would have had to lean forward. From this information, the wind velocity was estimated to be around 20m/s [5]. This strong wind occurred

probably because this hotel was located at a higher point in a valley where a wind from the building of origin is forced through a narrowing passage.

4. QUESTIONNAIRE SURVEY

Two months after the occurrence of the fire, a questionnaire survey was conducted concerning the distribution of fire brands at the time of the fire. The purpose of the questionnaire survey was to characterize a series of processes from fire brand generation to ignition and collect information on spot fires.

4.1 Method and contents

The questionnaire respondents were employees of the hotel from which the fire originated and local residents. The hotel employees were 40 individuals who were on duty on the day of the fire. These respondents were surveyed by the group survey method. Information from local residents was collected by the mail questionnaire method and the interview method. In the mail questionnaire survey, a questionnaire was sent to 249 households, and responses were collected from 52 households (response rate: about 21%). In the interview survey, local residents who were not covered by the mail questionnaire were surveyed, and questionnaire responses were obtained directly from eight individuals.

In the questionnaire, the respondent was asked to answer questions classified into three categories: "the condition of the fire of the building of origin," "characteristics of fire brands," and "spot fire damage." The questionnaire consisted mainly of multiple-choice questions.

4.2 Questionnaire results

1) Generation of fire brands

Figure 4 shows responses to the questions concerning the size and quantity of fire brands, which were included in the questionnaire to collect information on fire brands. As shown, the greatest number of respondents said that they saw

a "large quantity" of fire brands 5cm or smaller. At the time of occurrence of fire brands, the greatest number of respondents said that fire brands occurred when the wooden building was burning.

Figure 4. Size and quantity of fire brands

Figure 5 shows the relationships between the average flame height at the seat of fire and representative flame widths when fire brands were generated. As shown, the greatest numbers of respondents said that the average flame height was about 10cm and a representative flame width was about 20cm.

Figure 5. Average flame height and representative flame widths

To illustrate how far fire brands rose in the vertical direction, Figure 6 shows the maximum height reached by fire brands, and the vertical distance over which fire brands rose, which were calculated by subtracting the average flame height from the maximum height of fire brands.

As shown, the greatest number of respondents said that fire brands reached a maximum height of 15 to 20m, and that the height calculated by subtracting the average flame height from the maximum height reached by fire brands was about 10m. This means that in the vicinity of the building of origin, fire brands rose to a level equal to two times the average flame height and then were carried downwind.

Figure 6. Vertical distance over which fire brands rose

2) Distribution of fire brands

Table 1 shows the relationships between the locations of respondents and fire brand sightings. In the table, the numbers that follow a triangle (▲) are the numbers of respondents who said that there were no flying brands; the other numbers are the numbers of respondents who said that they saw flying fire brands. From the information contained in the effective responses, the distances and directions of fire brands from the center of the building of origin were determined. The directions were expressed by defining the north as 0° and measuring angles in the clockwise direction. As shown in Table 1, within the 0 to 100m distance range, fire brands were carried away in almost all directions. As the distance from the building of origin increased, however, the directions in which fire brands flew were gradually narrowed down to the range between 180 to 240°.

This means that in the vicinity of the building of origin, fire brands were carried away in almost all directions regardless of the wind direction, but

as the distance from the building of origin increased, the direction of movement of fire brands was affected increasingly by winds. The range of fire brand distribution determined from the questionnaire results show fair agreement with the investigation results shown in Figure 3.

Table 1. Relationship between the locations of respondents and fire brand sightings

Distance [m] \ Direction [°]	0-100	100-200	200-300	300-400	400-500	500-600	Total
0-30							0
30-60	1						1
60-90		▲1					1
90-120	1						1
120-150		1	▲2				3
150-180	2	1	1	▲1			5
180-210			2		1	1	4
210-240		4	2	1	1	1	9
240-270		4	4/▲2	2			12
270-300	1		1/▲1				3
300-330	1						1
330-360							0
Total	6	11	15	4	2	2	40

Table 2 summarizes the average values of maximum fire brand size for different respondent locations based on the maximum size of each sample of flying fire brands. In the table, "powdery" is represented by "1"; about 5cm by 5; about 15cm by 15; and about 30cm by 30. As can be seen from Table 2, fire brands tend to become smaller as the distance from the building of origin increases. At distances of 200m or less, large fire brands were conspicuous; at distances of more than 500m, only powdery fire brands were sighted.

Table 2. Average values of maximum fire brand size

Distance Direction [m] [°]	0- 100	100- 200	200- 300	300- 400	400- 500	500- 600	Ave.
0-30							
30-60	30.0						30.0
60-90		0.0					0.0
90-120							
120-150		30.0	0.0				10.0
150-180	30.0	15.0	15.0	0.0			15.0
180-210			10.0		1.0	1.0	5.5
210-240		15.3	3.0	1.0	5.0	1.0	8.2
240-270		1.0	3.0	8.0			3.6
270-300	5.0		7.5				6.7
300-330	1.0						1.0
330-360							
Ave.	16.5	12.0	4.9	4.3	3.0	1.0	7.6

Figure 7 a)~e) show the quantities of fire brands of different sizes and the distribution of

the maximum sizes of flying brands [6]. At distances of 300m or less in the southeast direction, fire brands of all sizes were sighted in large quantities. This indicates that powdery fire brands were scattered about widely. Examination of the distribution ranges of different sizes of fire brands reveals that as fire brands become smaller, the distribution zone of fire brands expands in the leeward direction. The range of distribution, therefore, is thought to be interrelated to the quantities of different sizes of fire brands and wind velocities shown in Figure 4.

a) In case of brand like "powdery"

b) In case of brand like "paper"

c) In case of brand like "sphere"

d) In case of brand like "board"

e) In case of brand like "stick"

Figure 7. Quantities of fire brands of different sizes and distribution of the maximum sizes of flying brands

3) Characteristics of fire brands

Table 3 and Figure 8 show the locations of spot fires caused by fire brands. Many spot fires occurred at distances of 200m or less from the hotel from which the fire originated. About 39.1% of the respondents residing within 200m from the hotel said that they were adversely affected by spot fires in one way or another. On the leeward side of the building of origin, spot fire damage occurred at a point more than 400m away from the hotel. Some of the respondents living in the immediate vicinity of the building of origin said that they were saved from spot fires because of the water applied by firefighters. Comparison of Tables 2 and 3 reveals that in the area where fire brands greater than 1 cm were flying, there was a possibility of a spot fire.

5. CONCLUSIONS

An investigation and a questionnaire survey were conducted to collect information on the distribution range of fire brands caused by a hotel fire that occurred in the Shirahama hot spring resort.

Table 3. Locations of spot fires caused by fire brands

Distance [m] Direction [°]	0-100	100-200	200-300	300-400	400-500	500-600	Total
0-30							
30-60							
60-90							
90-120							
120-150							
150-180			1				1
180-210	2				1		3
210-240		4	1				5
240-270	1	1		1			3
270-300							
300-330	1						1
330-360							
Total	4	5	2	1	1		13

Figure 8. Locations of spot fires caused by fire

The field investigation confirmed that the distribution range of fire brands is greatly affected by wind direction, and that topography, particularly complex topography, greatly affects the distribution range of fire brands because the topography alters wind velocity and wind direction. The investigation showed that the longest distance fire brands traveled was about 850m, and that the fire brand distribution zone about the building of origin had an angle of 85°. Several cases of tree fires caused by fire brands, which were confirmed in the investigation, indicated a high tree-fire risk.

A questionnaire survey was conducted to characterize a series of processes from fire brand distribution to ignition. As the first step, the relationships of the size of the seat of fire with the quantity of fire brands in the vicinity of the building of origin and the size of fire brands were determined. Examination of the relationships thus determined revealed that in the case of a wooden-building fire, smaller fire brands tend to be generated in a greater quantity. The effects of the shape and size of fire brands on their distribution range and spot fire damage were then determined. The questionnaire results concerning the distribution range of fire brands showed fair agreement with the investigation results. The questionnaire also revealed that in the area where fire brands larger than 1 cm are distributed, there is a possibility of spot fire occurrence, and that many spot fires actually occurred at distances from the building of origin of 200m or less.

The authors plan to further the characterization of fires and fire brands by analyzing photographs and videos of the building of origin at the time of the fire.

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