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OVERVIEW OF FIRES FOLLOWING THE GREAT EAST-JAPAN EARTHQUAKE

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ABSTRACT: The Great East-Japan Earthquake on March 11, 2011 actually caused large-scale and wide range fire damage. It may be said that the fire damage was equivalent or even larger in size and diversity of fire patterns, if comparing to the fire damages in the 1995 Hanshin-Awaji Great Earthquake. Also, this earthquake showed a distinctive feature such that there were quite many fires caused by tsunami directly and/or indirectly. As many of fires that occurred in the cities and towns, where there are coastal zone, were more or less affected by the tsunami, so we deemed them as "tsunami induced-fires" for the sake of convenience in the paper. On the other hand, the fires in the cities and towns, where there are not coastal zone, were not affected by tsunami, so we treated them as "earthquake-induced fires." Since the mechanism of occurrence of “tsunami-induced fires” differs largely from “earthquake-induced fires,” we think these two types of fires should be analyzed separately. In this paper, therefore, we describe the overview of fires following the Great East-Japan Earthquake such as regional distribution of fires and patterns of ignitions of both the above two types of fires. Also presented are the findings from the results of the analysis on the relation between the incidence of “earthquake-induced fires” and the seismic intensity in comparison with the data in the 1995 Hanshin-Awaji Great Earthquake.

Key Words: Great East-Japan Earthquake, post-earthquake fire, earthquake-induced fires, tsunami-induced fires, fire cause, fire pattern

INTRODUCTION

The earthquake on March 11, 2011, off the Pacific Coast of Tohoku (referred to as the Great East-Japan Earthquake below) was a colossal earthquake of a scale estimated to occur once every 1000 years. It caused damage of unimaginable proportions, starting with widespread and large-scale tsunami damage, followed by accidents at a nuclear power plant, the collapse of buildings and the spread of fire. All told, this disaster left the dead or missing who amount to roughly 20,000.

Although the damage caused by fire was perhaps not comparable with the tsunami and the accident of the nuclear power plant in terms of ferocity and severity, the fire damage was nonetheless large-scale and widespread, and there were a wide range of causes of fire outbreaks. On an absolute scale, it can be said that since the Great Kanto Earthquake, the scale and the diversity of fire damage in this earthquake is comparable only to that in the Great Hanshin-Awaji Earthquake. The investigation and elucidation of this fire damage is urgently needed, and the obtained knowledge will be extremely important for developing future fire prevention measures.

For example, aerial images taken by the Japan Air Self-Defense Force showing the scale and the extent of fires in the city of Kesennuma were broadcast on the evening news on the day of the earthquake, and the memory of these images is still fresh. The footage showed oil spilled from collapsed oil tanks and ignited in different ways, giving rise to fires (burning piles of wooden debris and petrol or crude oil floating on top of the tsunami) which ignited buildings along the coast and mountain forests and gradually spread to settlements and urban areas. Further shocking images, which were broadcast repeatedly, included burning buildings and debris floating on top of the tsunami as well as cars burning one after another. In coastal industrial areas, LPG tanks and oil refineries were also engulfed in flames.

Furthermore, the tsunami was not the only cause of fires. In Tokyo, where the intensity was between 5-lower and 5-upper in the seismic intensity of JMA (Japan Meteorological Agency) scale, 35 earthquake fires (distinguished from ordinary fires) emerged on that day, and one of the characteristics of this earthquake was that conventional earthquake fires were numerous despite the limited building damage. The limited damage can perhaps be explained with the distribution of the peak ground velocity, which is related to building damage. On the other hand, even if fires are not caused directly by the collapse of buildings, they can still emerge from upturned and fallen objects inside buildings, as well as from the failure of external lifelines (power lines, gas pipes, etc.), and therefore the cause of fires is not limited to the collapse of buildings. The building collapse ratio has been used as an alternative index of earthquake strength. However, even though there is a well-established correlation between the building collapse ratio and the fire outbreak rate, a causal relation between the two factors has not been confirmed. Therefore, to avoid widespread misunderstanding in the future, it is necessary to investigate a predictive model of fire outbreaks based on the seismic intensity index itself rather than on the relation between building collapse ratio and fire outbreak ratio.

Accordingly, this report first outlines the overall aspects of earthquake fires that emerged in the Great East-Japan Earthquake; then, these fires are separated into "tsunami-induced fires", which displayed distinct characteristics in this earthquake, and the well-known conventional "earthquake-induced fires", and important points about each type are mentioned.

EARTHUAKE-INDUCED FIRES AND TSUNAMI-INDUCED FIRES

Fig.1 shows a map with the locations of earthquake fires caused by the Great East-Japan Earthquake, which was prepared on the basis of the "Great East-Japan Earthquake report" issued by the Fire and Disaster Management Agency. Although some of the numbers given here are slightly different from those in the report, they were taken from data provided by local fire departments and it is unlikely that this affects the overall trend.

In Fig.1, circles in light gray represent the location of fires in the municipalities that suffered damage in the coastal area highlighted in Fig.2. A large number of these locations were affected in one way or another by the tsunami, and therefore in this report they are considered separately as so called tsunami fires (referred to as "tsunami-induced fires" below). There is a possibility that this category includes some conventional earthquake fires caused directly by the earthquake, such as fires in oil and gas tanks. We ask for understanding regarding such cases because, with the information gathered up to now, such fires cannot be distinguished from true tsunami-induced fires. However, tsunami-induced fires are considered separately from earthquake-induced fires for the city of Sendai since a clear distinction can be made in this case. On the other hand, circles in black indicate fires in municipalities which were not affected by the tsunami, in other words, they indicate known types of earthquake fires (referred to as "earthquake-induced fires" below).

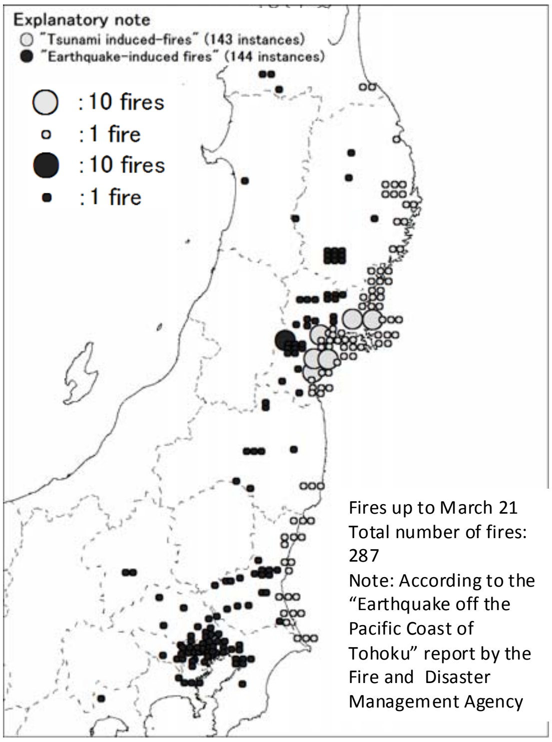

Fig.1 Fire outbreaks following the Great East Japan Earthquake.

Fig.2 Damaged municipalities along the coast.

The purpose of this endeavor is to analyze the relation between earthquake intensity (parameters such as seismic intensity and building collapse ratio) and the outbreak of fires. In performing a comparison with fires in previous earthquakes, earthquake-induced fires must be distinguished from tsunami-induced fires, which differ in terms of outbreak mechanism and counting, and therefore only the former type should be taken into account. Furthermore, the outbreak of extensive tsunami-induced fires in a number of areas, as well as the expansion of some of them into large-scale fires, must be investigated independently on the basis of information gathered through on-site surveys, witness accounts and numerous images. At present, material from various surveys has been processed and analyzed, and a concise description of this data is provided below.

RATIOS OF BUILDING COLLAPSE AND FIRE OUTBREAK WITH SEISMIC INTENSITY FOR EARTHUAKE-INDUCED FIRES

Here, we discuss the relation between the seismic intensity, the building collapse ratio and the fire outbreak rate with respect to the 126 instances of earthquake-induced fires, which are marked with black circles in Fig.1. In the Great Hanshin-Awaji Earthquake, the total number of fully collapsed buildings in the city of Kobe was about 67,000, amounting to 4,400 per 100,000 people (the population of Kobe at that time was about 1,520,000). In surveying fire-induced damage in the Great East-Japan Earthquake, a meaningful comparison can be made with fire-induced damage in the Great Hanshin-Awaji Earthquake. However, it is necessary to keep in mind the fact that at the time of the Great Hanshin-Awaji Earthquake, the seismic intensity in many disaster areas in Kobe was 7, while in the current case the intensity in most disaster areas was 6-upper or less.

Fig.3 shows the building collapse ratio plotted versus seismic intensity. In areas where the intensity in the Great East-Japan Earthquake was 6-upper, even if half of the semi-collapsed buildings are added to the number of fully collapsed buildings, the total number still amounts to only 523 per 100,000 people, which is about one order of magnitude lower than the abovementioned figure for Kobe. Also, there are almost no collapsed buildings in areas where the intensity was 5-upper or less. However, the correlation between seismic intensity and building damage is tentative.

On the other hand, Fig.4 shows the fire outbreak rate versus seismic intensity, and it can be seen that for areas with intensity of 6-upper, the fire outbreak rate is rather low at 0.65 per 100,000 people, with the highest fire outbreak rate being 1.00 per 100,000 in areas with seismic intensity of 6-lower. This is also one order of magnitude lower than the fire outbreak rate in the Great Hanshin-Awaji Earthquake, where the 175 instances of fire amounted to a rate of about 11.5 per 100,000 people. In consequence, in areas where the intensity was 6-lower for example, the number of fires versus thousand of collapsed buildings in the Great East-Japan Earthquake, which is 2.6, was quite similar to that for the Great Hanshin-Awaji Earthquake, which is 2.1, which leaves the question why the building damage was so limited in the Great East-Japan Earthquake to compare with that in the Great Hanshin-Awaji Earthquake.

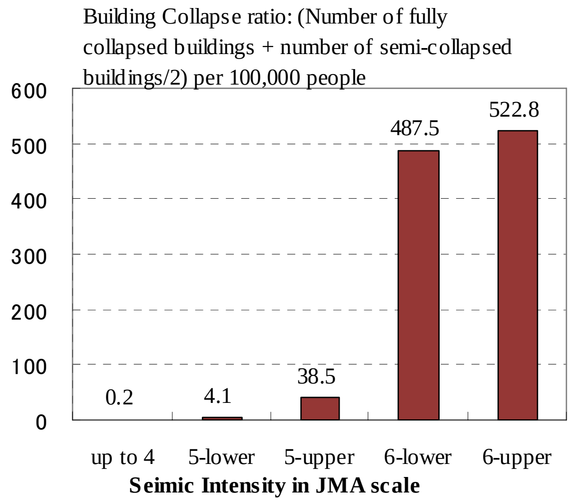

Fig.3 Building collapse ratio versus seismic intensity.

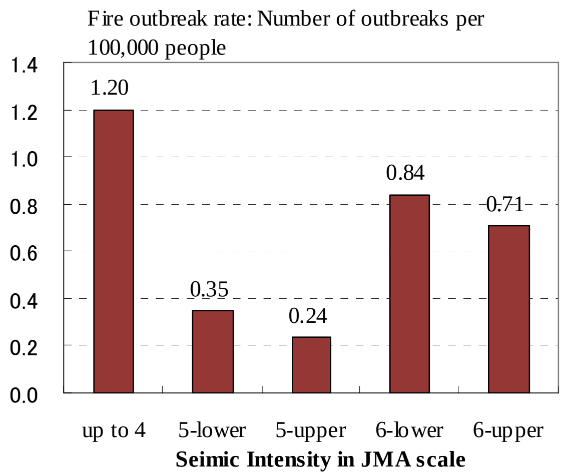

Fig.4 Fire outbreak rate versus seismic intensity.

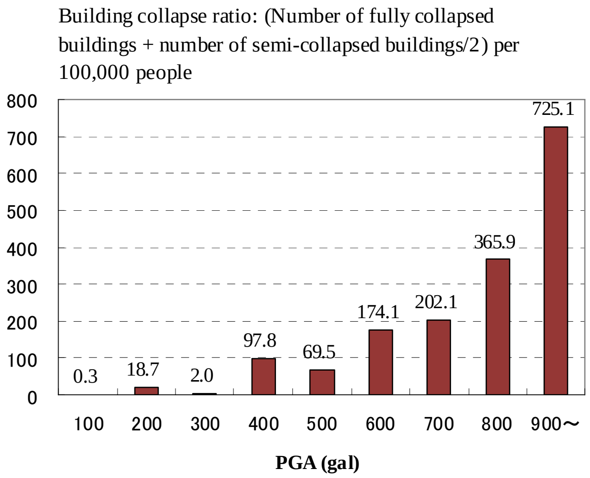

Fig.5 Building collapse ratio versus Peak Ground Acceleration.

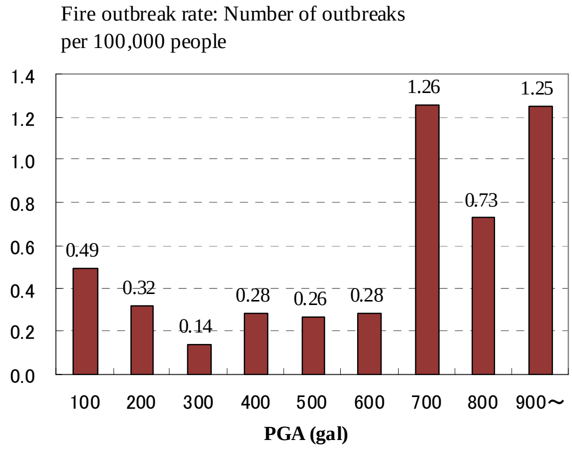

Fig.6 Fire outbreak rate versus Peak Ground Acceleration..

Fig.5 shows the building collapse ratio plotted versus peak ground acceleration (hereinafter called PGA). To compare with the relation between the building collapses ratios and the seismic intensity, a clear correlation is seen between the building collapse ratio and PGA. As PGA increases above 700(gal), the number of collapsed buildings per 100,000 people steeply grows and reaches 725 at 900(gal) if including the number of a half of the semi-collapsed buildings.

On the other hand, the correlation between the fire outbreak rates versus PGA in Fig.6 is not as clear as that seen between the building collapse ratio and PGA in Fig5. However, if comparing with the relation between the fire outbreak rates versus seismic intensity, the correlation between the fire outbreak rates and PGA is obviously seen. And, the fire outbreak rate grows drastically if PGA exceeds 700(gal). The impact of PGA on both the building collapse ratio and the fire outbreak rate should be investigated in more detail in the future work.

The characteristics of the Great East-Japan Earthquake in comparison with the Great Hanshin-Awaji Earthquake can be understood by looking at the building collapse ratio and the fire outbreak rate plotted in Fig.7 and Fig.8. A correlation between the building collapse ratio and the fire outbreak rate is difficult to derive for the Great East-Japan Earthquake in Fig.7, and in any case both parameters are low for areas where the seismic intensity was below 5-lower. On the other hand, for the Hanshin-Awaji Earthquake, there is a clear relation between the building collapse ratio and the fire outbreak rate seen in Fig.8, and the values for both parameters are high. Furthermore, Fig.9 shows a comparison of the building collapse ratio and the fire outbreak rate for each municipality where earthquake-induced fires emerged. The fire outbreak rate is high in areas where the building collapse ratio is low, and vice versa.

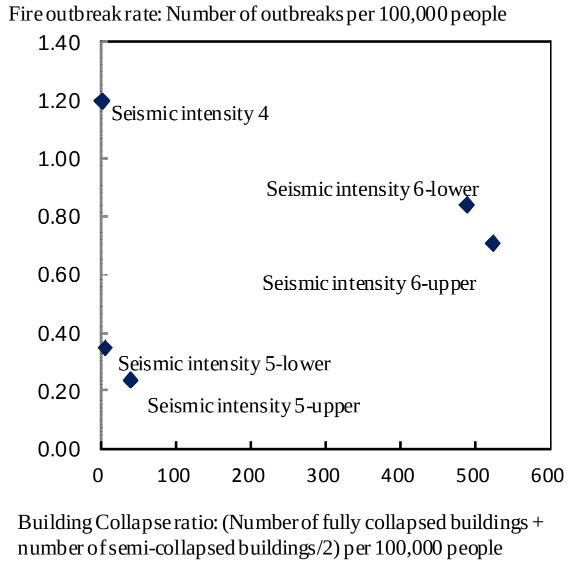

Fig. 7 Relation between building collapse ratio and fire outbreak rate in accordance with earthquake intensity.

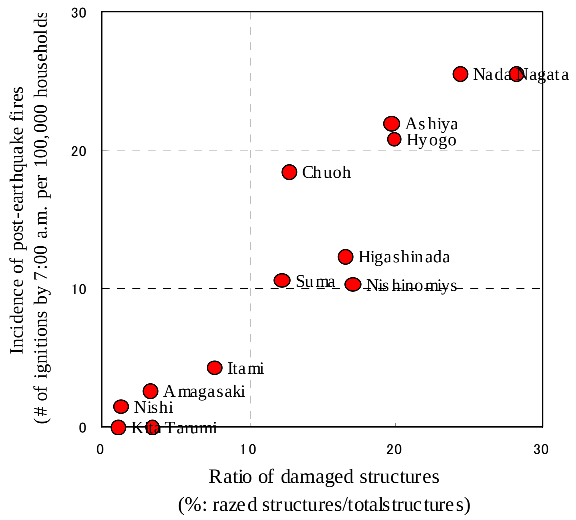

Fig.8 Relation between the ratio of fully collapsed buildings and the rate of fire outbreaks immediately following the earthquake (data for the Great Hanshin-Awaji Earthquake)

One conclusion that can be drawn from the Great East-Japan Earthquake is that there is no direct causal relation between building damage (such as of the ratio of fully collapsed to semi-collapsed buildings) and earthquake fires. Also, although modern buildings might not collapse, flammable objects located above utilities producing fire inside the buildings might be upturned or otherwise affected by the earthquake. Furthermore, lifeline systems such as power lines and gas pipes can be damaged by seismic motion, and fires might break out after the power supply has been restored. In this sense, in addition to avoiding the commonly held but mistaken notion that "fire outbreaks are related to the collapse of buildings", it is necessary to replace the conventional fire prediction model based on the relation between building collapse ratio and fire outbreak ratio with a new fire prediction model considering the mechanism according to which fires break out after earthquakes.

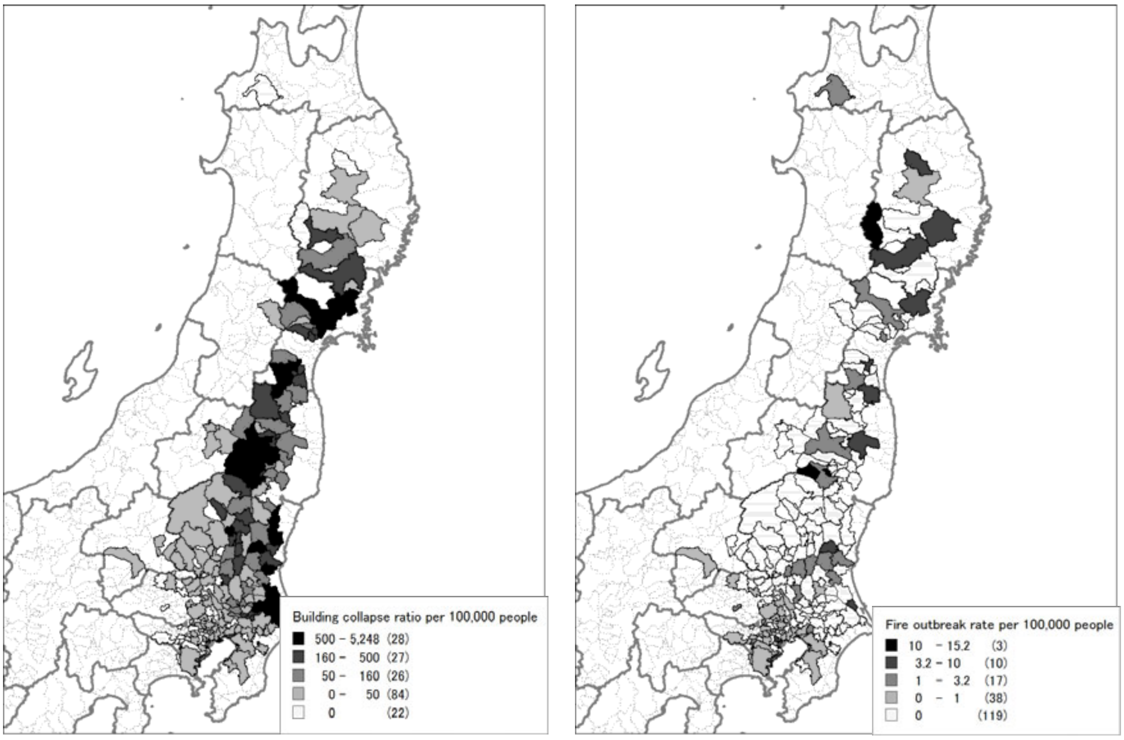

Fig. 9 Regional distribution of Building collapse ratio and Fire outbreak rate by municipality for earthquake-induced fires.

TSUNAMI-INDUCED FIRES

The Great East-Japan Earthquake induced a tsunami that inflicted severe damage on municipalities located in an area ranging from Iwate and Miyagi prefectures along the Sanriku coast to Fukushima, Ibaraki and Chiba prefectures. A large number of fires emerged in some of the municipalities in Iwate and Miyagi prefectures near the Pacific Ocean immediately after the direct damage inflicted by the tsunami, and several of those fires expanded into full-fledged urban fires. Tsunami-induced fires, shocking footage of which was broadcast on TV, were characteristic phenomena in the Great East-Japan Earthquake.

The causes of many of the fires in the municipalities along the coast shown in Fig.2 were related to the tsunami. Although these fires are referred to as tsunami-induced fires in this report, the provided numbers also include conventional earthquake fires caused directly by the earthquake, such as fires in oil and gas tanks. Although the complete picture of tsunami-induced fires is still unclear, the investigations have been undertaken by the various universities and laboratories. The obtained information is continuously disseminated, creating an environment of research collaboration in the form of information sharing between researchers, as well as between institutions, from the very beginning of the disaster, which is unprecedented in the field of fire research. The development and use of modern communication technology, such as the Internet and GPS, have played a major role in realizing such collaboration.

The overall picture of tsunami-induced fires will be discussed in future work, and the discussion in this report will be limited to a concise description of the outbreak pattern of tsunami-induced fires. Based on the information about fires available to the authors, various conditions can be pointed out as causes of tsunami fire outbreak.

(1) Spillage, ignition and flow of oil or LPG from upturned or collapsed storage tanks in industrial areas, and subsequent ignition of urban areas and buildings
(2) Spillage from upturned kerosene tanks and LPG cylinders in residential buildings, or spillage from broken distribution pipes
(3) Ignition of buildings by burning buildings or debris carried by the tsunami
(4) Ignition of buildings by burning ships or cars carried by the tsunami
(5) Acceleration of the oxidation of iron by salt contained in seawater, resulting in spontaneous ignition from heat trapped in mounds of debris containing iron

By the way, four fires emerged after the tsunami which devastated the Aonae area on the island of Okushiri following the 1993 earthquake off the southwest coast of Hokkaido. Two of these fires broke out on harbored ships, one building fire broke out in the urban area after the tsunami, and the fourth fire broke out in the inundated area from an unknown ignition source. The latter two were the sources of urban fires in Aonae as seen in Fig.10.

At the time, we surveyed the fire in Aonae on the island of Okushiri, but the causes of the tsunami-induced fires remained unclear. However, after witnessing the large number of fires that broke out throughout several prefectures as a result of the tsunami following the Great East-Japan Earthquake, it was strongly felt that the fires in Aonae were the manifestation of a universal phenomenon occurring after a tsunami rather than isolated events.

Difficulties associated with fire fighting activities should also be mentioned in regard to tsunami-induced fires. Naturally, the initial response is difficult due to evacuation. In addition, large amounts of debris block roads not only during, but also after the tsunami, thus obstructing the passage of fire engines and firefighters. Also, fire hydrants might become unusable due to damaged lifelines, which further obstructs fire fighting operations.

There are a number of other factors that play a role in the ignition and spread of tsunami-induced fires and the obstruction of fire fighting operations. Future measures for fire prevention and damage mitigation should be developed by making progress in surveys and research, as well as by elucidating all aspects and problems associated with tsunami-induced fires.

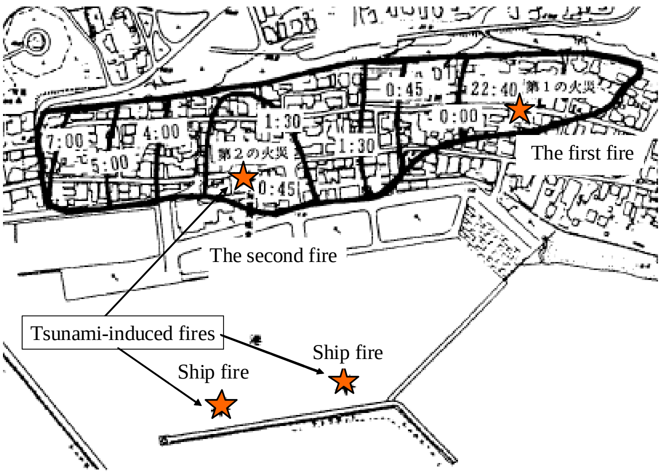

Fig.10 Post-earthquake fires after the South-West off Hokkaido at Okushiri island in 1993.

CONCLUSIONS: PROBLEMS TO BE INVESTIGATED IN FUTURE STUDIES

This report presents a summary based on a broad collection of materials, such as the surveys by ourselves, information published other researchers, articles and photographs from newspapers and magazines, news broadcasts and footage found on the Internet. The volume of written material, articles, photographs, footage and graphs is immense, and it is impossible to present all of it within the limited space available for this report. Therefore, an attempt was made to present a concise overview of the aspects and the characteristics of earthquake fires following the Great East-Japan Earthquake. Due to the limited time, this report inevitably contains inconsistencies and incomplete parts, and we ask for understanding in regard to such issues. By further advancing surveys and analysis in the future, we plan to develop and deepen our understanding on the subject while ensuring good accuracy.

Instead of a summary, the problems that should be investigated in future surveys and studies on earthquake fires are outlined below.

(1) Surveys and compilation of a database on earthquake fires and related information for each municipality.
(2) Analysis of case studies on tsunami-induced fires, analysis of the patterns of ignition and burning, elucidation of outbreak mechanisms and development of damage mitigation measures.
(3) Surveys on fires in factories in industrial areas, and elucidation of the causes of outbreaks, prevention measures.
(4) Elucidation of the outbreak mechanisms for earthquake-induced fires and development of a new prediction model for the fire outbreak rate.
(5) Investigation of fire outbreaks following the restoration of power supply (e.g., the relation between the time of power restoration and the times of fire outbreaks).
(6) The status of fire fighting activities, problems with acquisition and communication of disaster information, damaged fire hydrants and roads, and other obstacles impeding fire fighting activities.
(7) Investigation of the influence of sprinklers, fire alarms, fire doors and other fire safety equipment, as well as investigation of damage incurred by such facilities.

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