

ASPECTS OF FIRE OCCURRENCES CAUSED BY TSUNAMI

Tokiyoshi YAMADA¹, U HIROI² and Noriaki SAKAMOTO³

- ¹ Project professor, Department of Urban Engineering, The University of Tokyo, Tokyo, Japan, tyamada@fse.t.u-tokyo.ac.jp
² Research associate, Department of Urban Engineering, The University of Tokyo, Tokyo, Japan, hiroi@fse.t.u-tokyo.ac.jp
³ Research student, Department of Urban Engineering, The University of Tokyo, Tokyo, Japan, sakamoto@fse.t.u-tokyo.ac.jp

ABSTRACT: According to official reports, 286 fires broke out due to the 2011 off the Pacific coast of Tohoku Earthquake and its aftershocks. Approximately half of the fires occurred in flooded area following the great tsunami. Those fires have very unique aspects compared with other conflagrations followed by big earthquakes in the past. Investigations of those large fires were conducted in various districts. Some characteristic aspects of fires are introduced with case examples related to fire developing patterns and regional characteristics based on topographical and industrial features.

Key Words: Great East Japan earthquake, tsunami fire, fire investigation, urban fire, fire safety, escapes facility

INTRODUCTION

The tsunami triggered by the Great East Japan Earthquake mechanically destroyed various areas in the Sanriku coastal region, and moreover it caused a number of fires (hereinafter referred to as “tsunami fire”). In particular, Yamada Town in Iwate Prefecture (approx. 17 ha) and the Shishiori district in Kesenuma City, Miyagi Prefecture (approx. 12 ha) suffered from fires in town areas over a very wide range, exceeding the scale of the fires that occurred in town areas in Kobe City in the Great Hanshin-Awaji Earthquake (Mizukasa Nishi Park area: approx. 10.6 ha (Japan Association for Fire Science and Engineering 1996)). In spite of these facts, ordinary people may not have an image that a large-scale fire could occur in tsunami-flooded areas. Though many people at least must have known the occurrence of these fires on the night of the earthquake because numerous fires ominously floating in Kesenuma Bay were broadcasted on TV, the fires were gradually ceased to be reported, probably due to the explosion at the nuclear power station on the following day. Therefore, in reality, many people are not aware of the fires resulting from tsunami in this earthquake excluding people in the disaster areas.

Tsunami fires also occurred in the Aonae district of the Okushiri Island in the South-West off Hokkaido Earthquake in 1993. The fire spread area was approximately 5 ha, and 192 houses were destroyed by fire just after the tsunami arrival (Zama et.al,1993). It is also recorded in the past that in Kamaishi Cho (current Kamaishi City), one of the areas hit by the Great East Japan Earthquake, more

than 500 houses (officially recorded number: 294 houses) were burnt down by roaring flames in the Showa Sanriku Earthquake in 1958 (the Mainichi Newspapers 2011). From these facts, occurrence of a fire after a tsunami arrival may not be something special, but still, the authors do not know any such broad fires resulting from tsunami as we saw in this Great East Japan Earthquake in the past.

To gain the understanding of the overview of the tsunami fires, the authors conducted a series of field surveys on these fires that occurred in the Sanriku coastal region and around Sendai City after the earthquake. These surveys revealed that fires resulting from tsunami have different characteristics depending on topographical features and industrial characteristics of each region. This paper reports the characteristics of the tsunami fires that occurred mainly in the Sanriku coastal region and in the plain areas to the south of Ishinomaki City in Miyagi Prefecture, based on the findings from the field surveys.

FIRES RESULTING FROM TSUNAMI AND OUTLINE OF THE FIELD SURVEYS

Information to find the traces of the fires was started to be lost rapidly from the end of March to May 2011 after the earthquake, as the removal of the rubble progressed in these areas. During this period, a series of broad field surveys on the fires were conducted through information exchanges among universities and research institutes. The major purpose of conducting a series of surveys in this period is to understand how much area was burnt down by fire and to collect images and overall information.

Table 1 Sites of major fires resulting from tsunami surveyed by universities and research institutes

Sanriku coastal region	Iwate Prefecture	Noda Village 8 buildings including houses	Areas to the south of Sanriku region	Miyagi Prefecture	Tagajo City Petrochemical complex
		Otsuchi Town - Central town areas (Akasaki, Suehiro-cho, Kamicho, Honcho, Otsuchi Elementary School area) 10.8 ha - Otsuchi Junior High School area - Mast & Homac area - Akahama district			Miyagino ward in Sendai City - Town areas in Gamo 1 and 2-chome - Town area around Nakano Elementary School - A large number of warehouses around factories at Shiogama Port in Sendai City
		Yamada Town - Town areas from Hachiman-cho to the Nagasaki district 17.6 ha - Funakoshi Tanohama district - Workshops in the Osawa district			Ishinomaki City - 4 houses in the Hebita district - Town area in Kadonowaki-cho 5.3 ha
		Miyako City Town area in the Taroariya district 1.2 ha			Natori City - Town area in Yuriage 7-chome 1.1 ha - Rubble swept away to the Hiratabashi area
		Ofunato City - Factories in Sunagomae - Factories in Sakari-cho			Watari Town - 3 houses in Yoshidahama - Houses in Torinoumi, Arahama
	Miyagi Prefecture	Kesenuma City - Town area in the Shishiori district 14.2 ha - Town areas and forests in the Ohura district (east coast of Kesenuma Bay) - Town areas in Nainowaki, Benten-cho, and Shiomi-cho (west coast of Kesenuma Bay) - Forests in the Oshima district (isolated island)		Fukushima Prefecture	Iwaki City - Town area in Hisanohama Town 1.6 ha
		Minamisanriku Town Villages in Shizugawa Niida		Soma City - Collective areas in the Haragama district	
		Rikuzentakata City Kesen Elementary School gymnasium			

The enclosed figures are the areas of the fires estimated based on the field surveys conducted by the authors in the regions with a burnt-out area exceeding 1 ha.

Table 1 shows a list of major tsunami fires for which field surveys were conducted by universities and research institutes by around the end of May 2011. Some municipal fire departments also have conducted their own surveys, but their results are not listed in the table because reports of their surveys have not been released officially. The scales and the circumstances of tsunami fires range widely from the fires that spread in town areas in the Sanriku coastal region to a number of fires in independent buildings, such as factories and warehouses, in the Miyagino ward in Sendai City, and fires at the petrochemical complex in Tagajo City and those in ships in Kesenuma Bay. The paper introduces an overview of regional characteristics of tsunami fires .

CHARACTERISTICS OBTAINED FROM THE FIRE SITES IN THE SANRIKU COASTAL REGION

Tsunami fires generally occur by the following process: town areas and villages are uprooted by the tsunami; the rubble piles up and catches fire accidentally; the fire spreads over a wide area. This mechanism applies to both the Sanriku coastal region that has town areas at the back of narrow inlets and the plain areas with a broad flatland to the south of Ishinomaki City.

However, one of the characteristics of the fires that occurred in the Sanriku coastal region is that they not only occurred in town areas flooded by the tsunami waves but also spread over a wide area including forests. Some of the typical patterns of the tsunami fires in this region are as follows.

- 1) Houses, ships, vehicles, etc. are swept away by the tsunami waves from the seashore toward a hill (mountain). In particular, enormous quantities of wreckage pile up along a river, which is highly likely to spread fire. Few buildings collapsed due to the earthquake strength and none of fires that occurred before the tsunami arrived were reported. (Fig.1 (a))
- 2) A fire breaks out due to some shock when houses are destroyed or while they were drifting. Houses and fuels on fire start to drift toward the foot of the mountain. (Fig.1(b))
- 3) Enormous quantities of combustible materials, which were swept away toward the foot of hills (mountains) or fire-resistant buildings as rubble, catch fire and spread. (Fig.1(c))
- 4) The fire-fighting force is devastated by the tsunami attack, and moreover fire extinguishing activities are disturbed by the rubble and other obstacles, leaving the fires uncontrolled and spreading them to forests. Evacuees were forced to be evacuated to another place in some evacuation sites. (Fig.1(d))

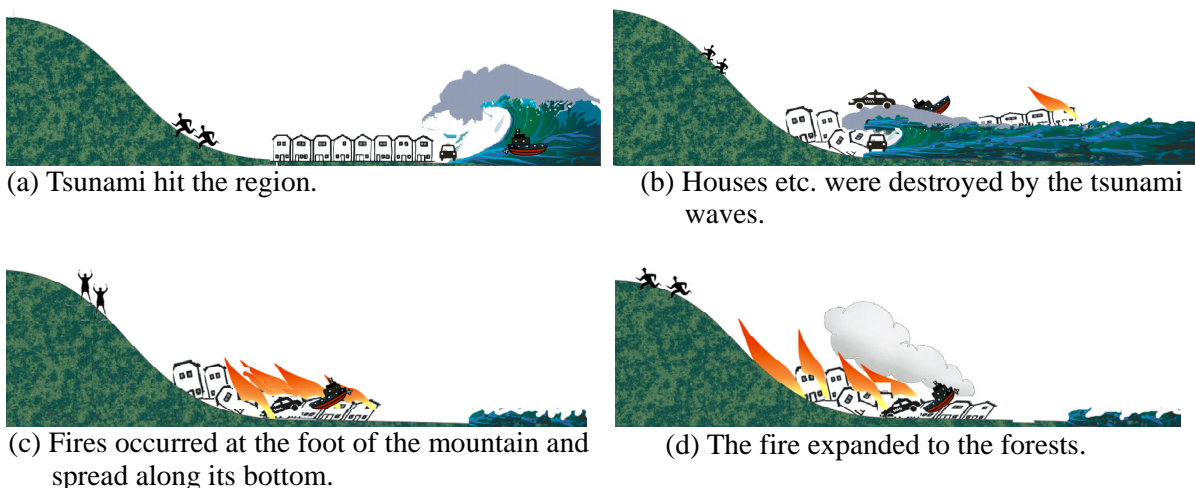


Fig. 1 Image of the general mechanism of the fires resulting from tsunami in the Sanriku coastal region

As a result, fires that spread in many town areas of the Sanriku coastal region expanded along the foot of a mountain in a band shape, and people who had evacuated to evacuation facilities standing on hills, such as schools, were forced to be evacuated to another place in Otsuchi Town, Yamada Town (Funakoshi Tanohama district), and some other towns. The following introduces the details of the fires in Otsuchi Town and Taro Town in Miyako City as typical cases of fires that occurred in the Sanriku coastal region, and those in Kesenuma City as unusual cases of fires.

Fires in the town area of Otsuchi Town in the Shimohei district

Fig. 2 shows the GPS tracks that the authors recorded by walking the fire sites along the outer edge of their fire spread area, and burnt-out ranges estimated by visual checks. According to videos posted on the Internet (Yomiuri Streaming 2011 and Jijicom 2011), a large number of fires occurred in this region of Otsuchi Town at around 3:38 pm on March 11, 2011. Then, fires occurred separately in the town area at least at three places along the mountain foot and at one place in front of Otsuchi Station (the areas circled in Fig. 2 (b)) at around 5:30 pm, which were nearly spreading to forests. At Otsuchi Elementary School (Fig. 3 (a)), which was an evacuation site, a fire from cars parked outside the school building spread into the building after the first floor was flooded.

Another fire approached a community center, which was another evacuation center standing on a hill, exposing the center to danger of a forest fire (Fig. 3 (b)). According to interviews with the local volunteer fire fighters, the force of the flames increased along the mountain, spreading to the west edge. Therefore, they set up a line to prevent the fire from spreading at the west edge of the town area along a river, and successfully prevented the spread by using the river water. Meanwhile, the forest fire that spread to the mountain at the back of the school also expanded to the Kamaishi area, burning a far larger area than the fires in the town area. It is reported that a houses over the mountain was also burnt down.

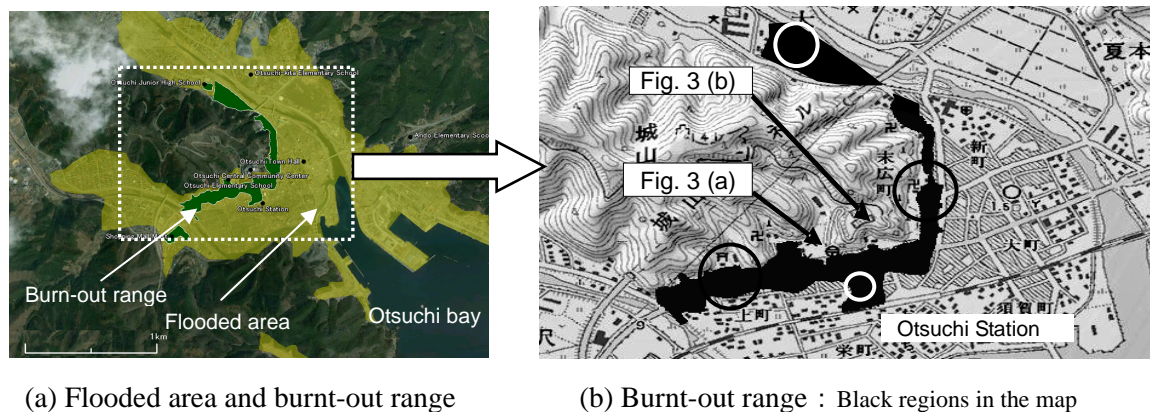


Fig. 2 Burnt-out range of the fire in the town area of Otsuchi Town

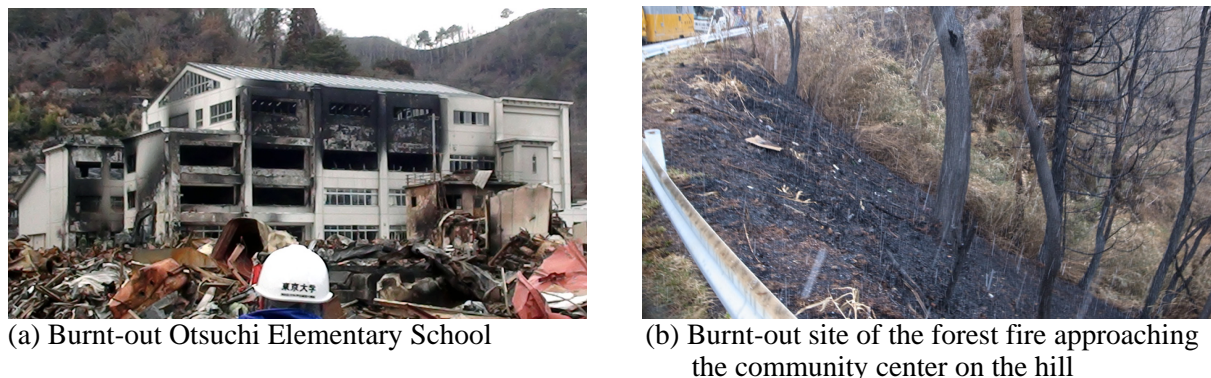


Fig. 3 Fire sites in Otsuchi Town: Photos taken on March 27, 2011

Fires in the town area of Taro Town in Miyako City

The tsunami waves rushed in Taro Town overwhelming its famous 10-meter tall coastal levee, and ran up a river extending to the north. It also swept away destroyed houses and other various objects to the narrow Ariya district, where a fire occurred along a mountain (Fig. 4, Fig. 5). The fire seemingly occurred in one area, but local interviews revealed that houses on fire separately flowed into the site, and the fires occurring from two places spread broadly (the areas in the enlarged view shown with the arrows). A fire in the town area developed into the northern forests in this district, too. Fig. 5 (b) shows burnt trees standing on the slope at the north edge of the fire spread region. It is found from the photo that live trees were burnt and carbonized, indicating a very strong force of the flames in this region.

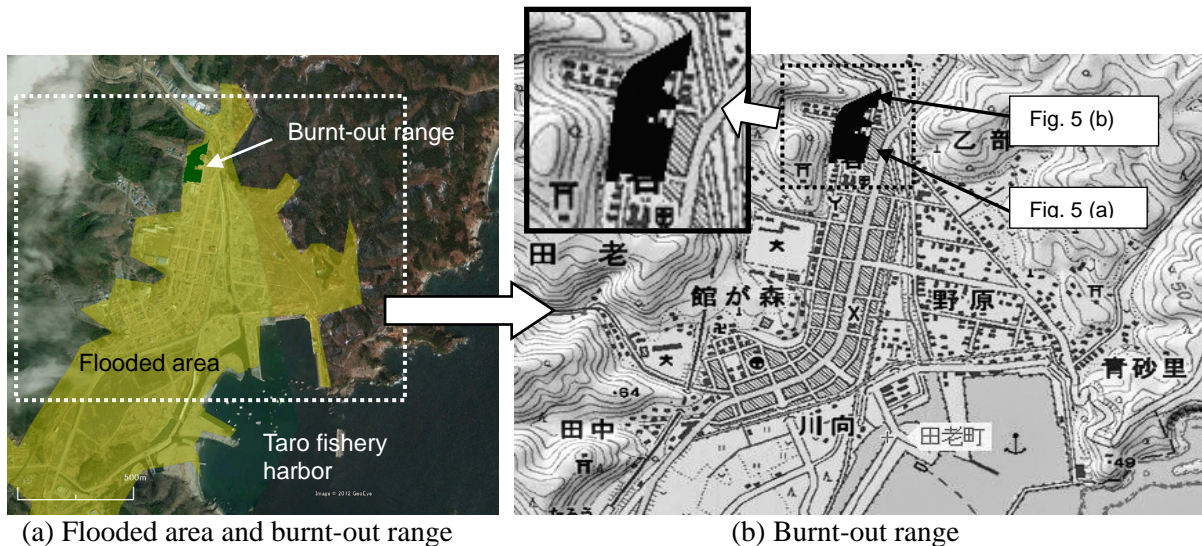


Fig. 4 Burnt-out range of the fire in the town area of the Ariya district, Taro Town, in Miyako City

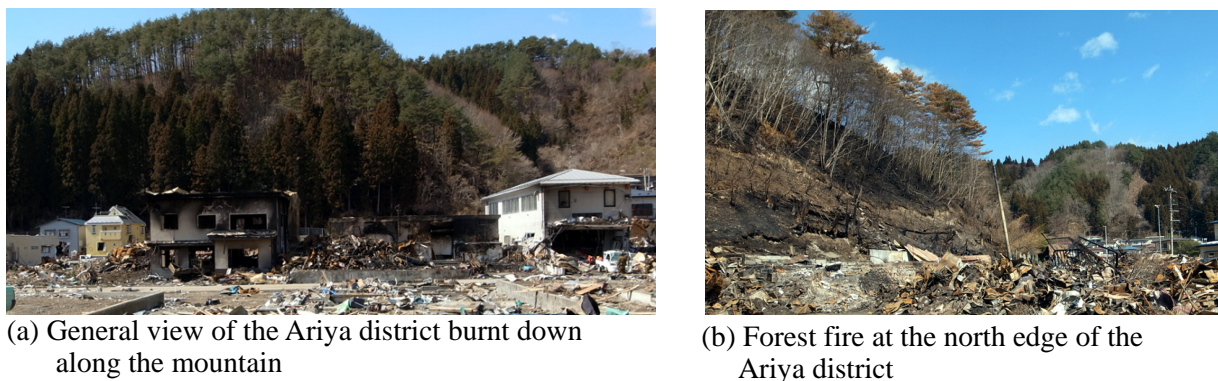
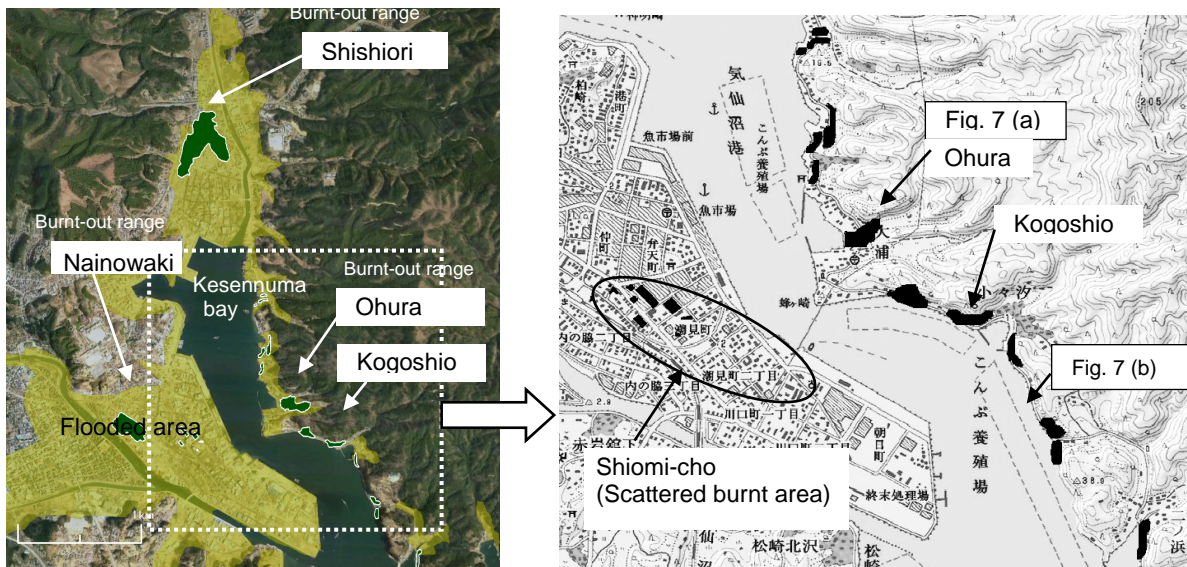


Fig. 5 Fire site of the Ariya district, Taro Town, in Miyako City: Photos taken on March 28, 2011

Fires in the town areas in Kesenuma City and its surrounding areas

The fires that occurred in Kesenuma City spread over a very wide area as shown in Fig.6, and causes and conditions also differed greatly. Therefore, it could be unusual fire patterns in the Sanriku coastal region. In the Shishiori district (an area of approx. 12 ha was burnt down) in the north of the city, the second largest fire in the town area after that in Yamada Town occurred. The northwest area of this region is surrounded with mountains, and rubble is apt to pile up by the tsunami waves running up along the river. This geographical condition seems similar to that of the regions described above.

The greatest difference we can see in the fires that occurred in the Kesennuma region from those in other regions is that both the floating rubble and spilled fuels brought a number of floating fire sources onto Kesennuma Bay, which triggered the spread of fires to the buildings, such as warehouses, over a wide area at the port district in the south of Kesennuma City. The fires spread further into ships in Kesennuma Bay, as well as villages and forests over a wide area in the east coast including the Kogoshio district. It is reported that in Oshima (Big island) , located in the south area, a fire from the coast ran up the northern foot of Mt. Kameyama, the highest mountain in the island, scaring the evacuees at the elementary school used for evacuation center in the south area. Fires also occurred in other town areas broadly including Nainowaki where fires started three days after the earthquake.



(a) Flooded area and range of the fires

(b) Fire sites of the coastal area of Kesennuma City

Fig. 6 Fire sites in Kesennuma City



(a) Fire spread area in Kogoshio:
The circles show various objects swept away by the tsunami waves, such as oil drums, gas cylinders, and other fuel containers



(b) East coast in which the fire spread from the sea surface to the forests

Fig. 7 Fire sites of the east coast of Kesennuma City: Photos taken on March 29, 2011

CHARACTERISTICS OF FIRES RESULTING FROM TSUNAMI IN THE PLAIN AREAS TO THE SOUTH OF MIYAGI PREFECTURE

The areas to the south of Ishinomaki in Miyagi Prefecture have different geographical features from those of the Sanriku region where mountains are close to the sea. Instead of the foot of mountains, fires occurred in these areas from hills, river banks, and buildings, where the rubble piled up. Fires that occurred in the Kadonowaki district in Ishinomaki City and Shizugawa in Minamisanriku Town are typical cases. Another characteristic of fires resulting from tsunami in plain areas is that the concentration of the population and industries caused fires of slightly different properties from those that occurred in the Sanriku coastal region. The following introduces how the fires occurred in some typical regions in these plain areas.

Fires in the town areas of the Kadonowaki district in Ishinomaki City

The Kadonowaki district in Ishinomaki City is located in a low plain area with a high hinterland in the north side. As shown in Fig.8, the whole area surrounding the hill was flooded by the tsunami waves. The fire that occurred in this flooded area over a wide area spread linearly along the south side of the hill where the tsunami waves arrived. That means, it can be estimated that the rubble swept away by the tsunami waves piled up at the foot of the hill and the fire spread there, as with the fires in the town areas of the Sanriku coastal region that stretch out along the mountain foot. Since a residential district spreads out in the northern hill, the fire might have spread to this area, but it was prevented by fire extinguishing activities from the hill.

One of the characteristics of the fires in this region is that it resulted from a fire that broke out in cars parked at Kadonowaki Elementary School in Ishinomaki City. According to the interviews, a lot of cars used by evacuees were parked in the schoolyard before the fire occurred, however some of them were swept away by the tsunami waves, and they were crashed into the building and burst into flames, which spread and expanded to the school building. Though the first floor of Kadonowaki Elementary School escaped the fire because it was flooded by the tsunami waves, the external walls of the second and third floors still have the traces of severe heating applied externally by the fire of these cars. While the right (east) half of the building was burned from the first to the third floor, the fire did not spread to some part of the first and second floors of the left (west) half. Some of the estimated unburned reasons are that these floors had been flooded and that the windows and the doors had not been damaged severely, which prevented the fire spread.

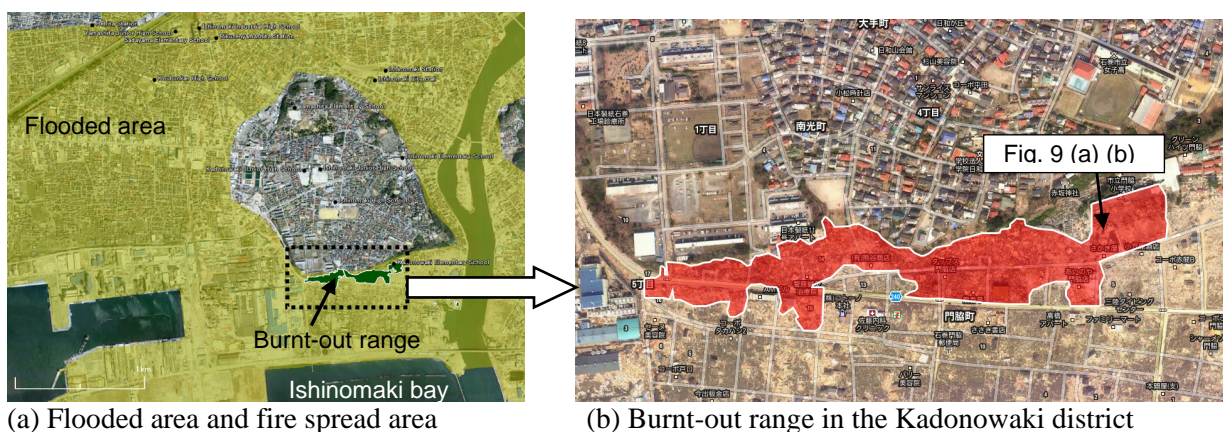


Fig. 8 Burnt-out range of the fire in the town area of the Kadonowaki district in Ishinomaki City



(a) Burnt-out site on the south side of Kadonowaki Elementary School



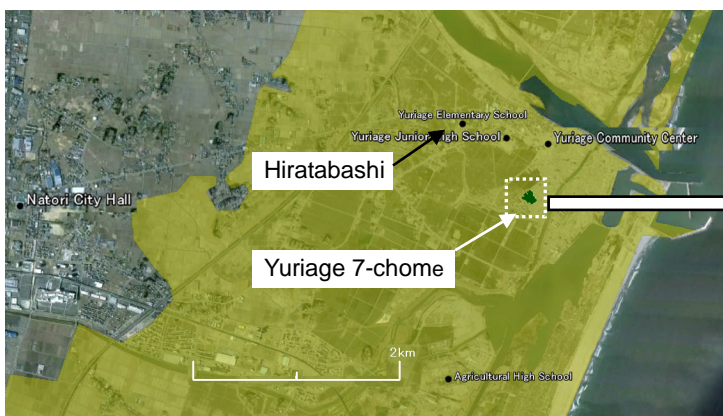
(b) Cars reported to be a source of the fire spread

Fig. 9 Burnt-out site of Kadonowaki Elementary School in Ishinomaki City:
Photos taken on April 10, 2011

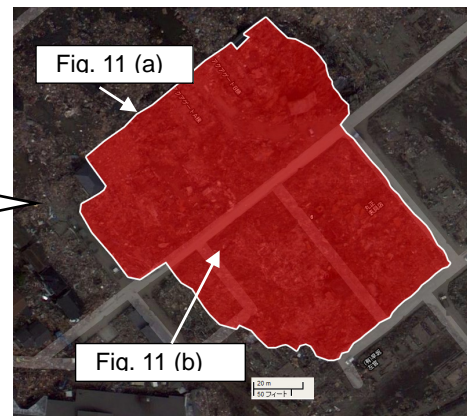
Many residents had evacuated to this elementary school after the earthquake, but the approaching danger of fire made them evacuate to another place. Therefore, they decided to evacuate from the north side of the school building to the adjacent hill. They said that they descended to the roof of the storage room from the connecting corridor on the second floor because the first floor was flooded, and then used a platform as a ladder to barely evacuate to the hill.

Fires in the town area of the Yuriage district in Natori City

In the flooded areas in Natori City, fires occurred in two places: the Yuriage 7-chome district and the Hiratabashi area. The fire in Hiratabashi chiefly resulted from objects swept away to a river bank, and it spread over an area of 150 m, which is different from sort of a fire in the town area. In contrast, the Yuriage district that suffered from a fire in the town area is a new residential district constructed in a flatland located about 1 km inland from the coastline. As the aerial photographs in the newspaper etc.(Mainichi JP 2011) showed the fire immediately after it broke out, it is estimated that a fire occurred in the rubble piled up around the houses that had not been swept away by the tsunami waves, and it spread to the surrounding area after the water receded. Since paddy fields spread out along the boundary in the northeast area where the fire stopped to spread, and the rubble was scattered around over a broad area, the flames did not spread further.



(a) Flooded area and fire spread area



(b) Fire spread range in the Yuriage 7-chome district

Fig. 10 Fires in the town area near the Yuriage district in Natori City



(a) Boundary of the fire spread in the northwest area



(b) Propane gas containers accumulated at the site

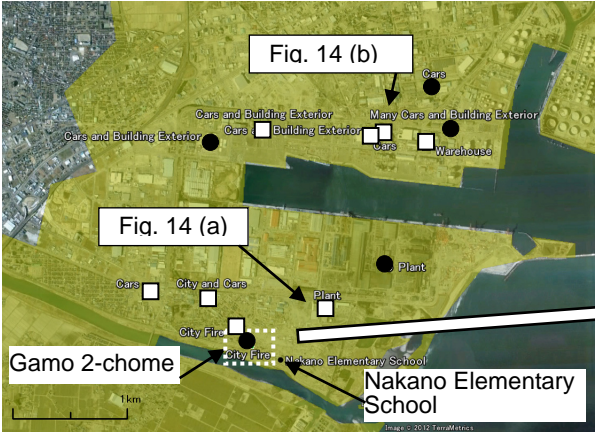
Fig. 11 Fire site of the Yuriage district in Natori City: Photos taken on April 10, 2011

What was noticeable in this region is that a number of burnt or exploded propane gas containers were accumulated. We can see from various videos posted on the Internet (YouTube 2011) that propane gas containers installed at each house were swept away by the tsunami waves, and the gas blew out due to a breakage or the operation of the pressure relief valve at a crash into another object, catching fire from some sparks and bursting into flames. Though the propane gas cannot be identified as the source of the fires in this district, it could be concluded that energy sources including propane gas used for daily life can make a significant contribution to an outbreak or spread of fires in residential districts such as Yuriage.

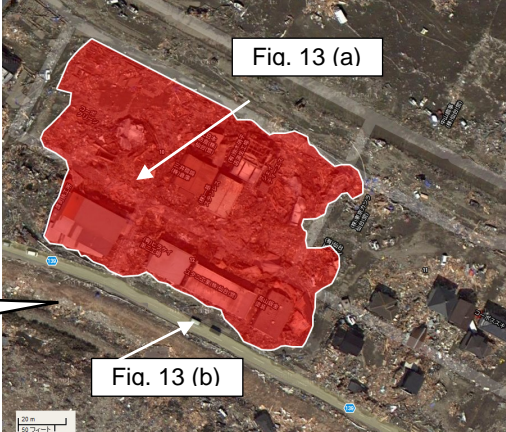
Fires in the port region of the Miyagino ward in Sendai City

Fig.12 shows the sites of the fires that occurred in the water area at the port of the Miyagino ward in Sendai City. The sites marked with “●” in the map show the fires that occurred on March 11, 2011 when the earthquake occurred; the sites marked with “□” show the fires that occurred on March 12 to 13. This region is close to the port, and it is also an industrial area packed with large warehouses and factories as an industrial complex.

The fires in the town area in this region broke out at three places around Nakano Elementary School, an evacuation site, where smaller factories and workshops were concentrated along a river.



(a) Flooded area and fire spread area



(b) Fire spread range in the Gamo 2-chome area

Fig. 12 Fire site in the port region of the Miyagino ward in Sendai City

Though the burnt-out area was limited, the evacuation building may also have been on fire, if the fire spread to Nakano Elementary School because of the rubble accumulated at the foot of its building, bringing an extremely serious problem to the evacuees who were isolated in this flooded area.

Out of these three fires, the largest one occurred in the Gamo 2-chome area (approx. 0.8 ha, about 20 buildings were burnt down). These buildings were located along a river bank, which is geographically apt to accumulate piles of rubble and vehicles. It is not known which of the leading waves or drawbacks of the tsunami brought these rubble and vehicles to this area, and the rubble accumulation conditions are also different between the north side of the building in the burnt-out area and the opposite river bank side (south side) as shown in Fig.13. The broken condition of shutters and crash situations of vehicles indicate that these piles of rubble flowed into the building from the north side in the same direction.



(a) Fire spread region in the north area where piles of rubble such as vehicles accumulated



(b) Broken facilities on the river bank side (in the south area)

Fig. 13 Fire site in the Gamo 2-chome area: Photos taken on April 9, 2011

Another characteristic in the port district of the Miyagino ward is that numerous vehicles were burnt. Many vehicles were parked in this distribution center, and additionally it is reported that a number of cars were washed out from the integrated yard at the wharf by the tsunami waves, which are estimated to have contributed to the outbreak or spread of the fires in the buildings. Almost equal numbers of vehicle fires occurred immediately after the tsunami arrival and over the following days. Residents said that hundreds of vehicles were burnt after March 11 in Minato 4-chome. Though it is still unknown whether these subsequent vehicle fires were caused by a failure in the electrical systems



(a) The first floor was destroyed by the tsunami and fire



(b) Piles of rubble such as vehicles were swept away toward the building, causing a fire

Fig. 14 Fires in the industrial facilities in the port region of the Miyagino ward in Sendai City: Photos taken on April 9, 2011

arising from a submergence in salt water, there were also cases in the past where vehicles submerged in salt water due to a high tide burnt, and so there would be still room to study about the relationship between a submergence in salt water and the vehicle fires that occurred in this region.

There are also other cases where a warehouse or a factory was burnt a few days after the earthquake. Most of these buildings had their first floor flooded and the external wall swept away by the tsunami waves as shown in Figure 14 (a). It is unlikely that the fires in these industrial facilities were caused by restored electricity few days later because the power was not supplied from outside. The further investigation into the causes of the fires in each individual facility and release the results are expected in order to prevent similar fires hereafter.

CONCLUSIONS

Nearly half of the reported 286 fires (Fire and Disaster Management Agency 2011) that occurred in the Great East Japan Earthquake resulted from the tsunami. Characteristics of these fires differ greatly among regions. Typical fires that occurred in the Sanriku coastal region arose from a lot of combustible materials, such as houses and vehicles, which were destroyed and swept away by the tsunami waves toward a mountain, caught fire from a source of fire (domestic and other various fuels) drifted there, and spread into town areas and forests. On the other hand, in plain areas where the population and industries were concentrated, a small number of fuels, such as household gas cylinders and vehicles scattered about the town, joined together into a mass of combustible materials, which are estimated to have made a great contribution to potential outbreak or spread of fires.

In any region, it is estimated that tsunami fires were caused by a combination of various potential factors such as an electric leakage, a short circuit, and sparks from a crash, but most of them are accidental factors and it would remain difficult to investigate the true causes. This is because it is quite difficult to reproduce the fire phenomena that resulted in fires in town areas using experimental techniques due to the large population parameters, though the probability of occurrence of individual phenomena is very small. In fact, a lot of videos posted on the Internet show flames and smokes that did not result in a fire disaster. The authors consider that it will become necessary to examine a lot of possibilities by stimulating the imagination while continuing to collect necessary information in order to find out the causes of the tsunami fires and how they spread out, as well as to take various measures according to each regional characteristic.

Finally, one of the similar characteristics in the regions where tsunami fires expanded is that the fires expanded as the local fire-fighting force was severely diminished due to the tsunami. The fires were left uncontrolled for about two days until emergency fire response teams arrived at the sites and started fire extinguishing activities, exposing earthquake victims to another danger from the fires. This threw down an important challenge to people engaged in firefighting as to how to continue fire fighting operations in case of an earthquake disaster to protect local residents from tsunami fires.

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