Randy Dutton

Here is my official comment on the Department of Natural Resources Underground Storage Tank Rule.

I recommend Washington State Department of Ecology implement a building code change that retroactively requires liquid fuel private, commercial and government fuel stations, which are located in a potential flood or tsunami inundation zone, which for Grays Harbor County should be at least the 40' elevation line, have backflow preventers to prevent the entrance of any foreign solids or liquids. Also, all vents, fuel lines and electrical systems to support fuel operations shall be protected with a method designed and constructed to meet the structural requirements of debris impact commensurate with a tsunami flood.

Further, if the facility does not have a permanent onsite optional stand-by generator, that is protected from flood waters and/or debris impact, to operate the normal branch electrical system, there shall be a permanently installed predesigned water-proof electrical service entry for the normal branch electrical system that will allow a quick connection to a temporary electrical generator. This quick connection shall be installed inside of a permanent metal enclosure rated for this purpose and may be located on the exterior of the building.

Said water proofing should be designed for a minimum 28psi. (about 30 feet immersion depth).

Currently coastal Washington has fuel stations that WILL be submerged in a tsunami inundation. For example, I discovered that MASCO has 6 of 8 fuel facilities in Grays Harbor County that are in the inundation zone and they do NOT have backflow preventers. Further MASCO has a group of tanks at their main office that are on supports that will Not resist a surge and thus will add to contamination and fire threat). They are not alone. Research shows many of coastal fueling stations have vents that will NOT prevent contamination by flood waters and/or damage by surge debris. Not only does contaminated fuel present an environmental pollution threat and fire threat, but coastal Washington needs ALL the fuel we can get immediately following a megaquake and tsunami. We should not permit fuel to be contaminated when lives and recovery count on it.

I have asked my state representatives and state senator to promote this change and have gotten no response.

Regards,
Randy Dutton

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Mechanism of tsunami fires after the Great East Japan Earthquake 2011 and evacuation from the tsunami fires

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Abstract

The tsunami after the Great East Japan Earthquake on 11 March 2011produced a huge impact under which various oil tanks at ports and industrial complex and gas cylinders at homes, automobiles, etc. were damaged and caused hazardous materials such as gas and gasoline in those oil tanks, gas cylinders and fuel tanks to leak. In these situations, sparks from metals which collided each other by tsunami and through other scenarios may have ignited leaked combustible gases and gasoline to become fires. These fires spread to combustible materials in and from broken houses, automobiles etc. near around. Ignited broken houses, automobiles, fishing boats and other combustible materials floating with tsunami waves spread fires to accumulated combustible materials swept away by tsunami from broken houses and landed floating housesat stagnated points near banks and hillsides. There were also some cases that leaked gases from gas-cylinders and leaked gasoline from fuel tanks of automobiles under the accumulated materials have caused fires according to witnesses of residents. Leaked oil from tanks may have contributed to the combustion in these circumstances. In these ways, fires broke out at various places throughout the tsunami affected region and some escalated to large-scale urban fires especially in wooden urban areas. Many of the people that had been evacuated from the tsunami-affected zone to tsunami refuge buildings had once again to be evacuated to avoid the spreading, escalating fires. The fire spread area was wide, and it is commonly recognized among researchers of universities and research institutes that cooperation is necessary to share information of earthquake fires and tsunami fires. This paper is mainly based on an interim report of this kind of cooperation organized by the Japan Association for Fire Science and Engineering (2011).

Keywords: Tsunami fire; Leaked gases; Accumulated combustible materials; Tsunami refuge building; Secondary evacuation

1. Status of fire breakouts

According to the Fire and Disaster Management Agency (FDMA) , the number of the 2011 Great East Earthquake and Tsunami related fires is 286. Sekizawa et al. [2] conducted a questionnaire survey to fire departments in affected regions about six month after the fires. The result is shown in Table 1. There were 124 tsunami fires and the percentage of tsunami fires was high in Iwate and Miyagi prefectures where about 20 to 65 percentage of built-up land area of coastal municipalities were inundated by the tsunami [3]. FDMA decided to count merged fire as one fire [4]. Fire Departments followed this decision. From the standpoint of emergency handling, this counting system is understandable, but for pursuing mechanism of tsunami fires, it is better to count each fire occurrence. For example, in Ootsuchi Town at least six fires occurred in one large merged fire area, in Ishinomaki City at least five fires occurred in one large merged fire area as shown in Fig. 1 according to aerial videos, photographs and interviews to local people who were by the fire sites.

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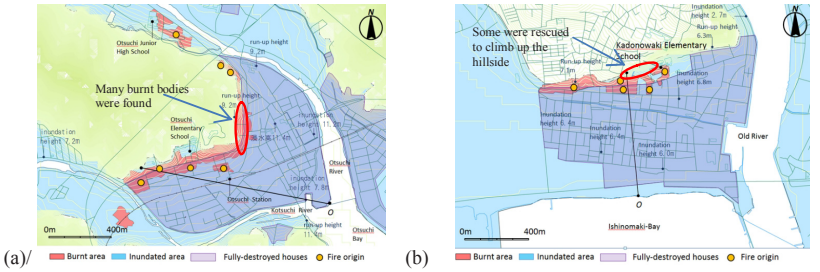
Besides these enlarged tsunami fires there were many small fires as shown in Fig. 2 which were not officially recorded because the evidences of these small fires were swept away by tsunami waves. In order to estimate the tsunami fire occurrences and to consider countermeasure against these fires, it is necessary to collect data of these fire occurrences.

Table 1. The number of fires related to the 2011 Great East Earthquake and Tsunami

	Result of a questionnaire survey to fire brigades in affected regions (2012) Fires occurred from 11 to 31 March, 2011 (Data from 11.7% brigades are missing)				Official Record
Prefecture	Tsunami Fires	Earthquake Fires in coastal regions	Earthquake Fires in inland regions	Total	(Number of Fires)
Aomori	6	1	3	10	5
Iwate	24	0	9	33	34
Miyagi	82	25	10	117	135
Fukushima	4	5	12	21	11
Ibaragi	8	5	13	26	31
Akita	-	-	-	-	1
Gunma	0	0	2	2	2
Saitama	0	0	11	11	16
Chiba	0	0	11	11	12
Tokyo	0	0	32	32	33
Kanagawa	0	0	6	6	6
Total	124	36	109	269	286

Questionnaire survey to fire brigades in affected regions: Sekizawa et al. [2]
Official record: FDMA [3]



(a)/ (b)

Fig. 1. Fire occurrence points (estimated fires origins) in merged tsunami fire areain (a) Otsuchi townand (b) Ishinomaki city. The fire occurrence ratio is about one per 200 meters in burnt area along hillside where combustible materials from broken houses and floated houses were accumulated.

(a) around 15:50, 11 March 2011, Yuriage, Natori, Miyagi [5]

(b) 15:46, 11 March 2011, Rikuzentakada, Iwate [6]

Fig. 2. Small fires circled with red dotted lines (a) at front line of tsunami waves in front of Yuriage Junior High School in Natori city and (b) beside Rikuzentakada city hall where were flooded by tsunami waves. (a) combustible gas ejected from gas-cylinder or tanks is shownwith a yellow doted circle.

2. Tsunami-induced fire breakout patterns

Three main breakout patterns of tsunami-induced fires were recognized through investigations carried out by the Japan Association for Fire Science and Engineering [1]. All of these main patterns are related to hazardous petroleum facilities which potentially discharge combustible gases in case. Containers of any hazardous material were destroyed by tsunami and ejected combustible gases were ignited by any sparks just after the arrival of tsunami.

2.1. Tsunami-induced fire related to leak from liquefied propane gas cylinder at home (LP Gas Cylinder Pattern)

In the tsunami affected area, liquefied propane gas cylinders were widely used as primary heat source. Decrease of cylinder supplied households were about 22,000 in Iwate prefecture, about 88,000 households in Miyagi prefecture[7]. Since usually each household was supplied two cylinders as shown in Fig. 3(a), there seems to be about 44,000 cylinders in tsunami inundated area in Iwate prefecture, about 176,000 cylinders in tsunami inundated area in Miyagi prefecture respectively.

When tsunami hit a house with cylinders as shown in Fig. 3(a), cylinders were disconnected and floated into tsunami waves. Some valves and gas-pressure regulator of cylinders were destroyed when thehouses were hit by tsunami as shown in Fig. 3(b). Then propane gas leaked and caused fires inside of the floating houses. Sometimes propane cylinders rolled and floated on the water with the flame jet which ignited the fire on buildings or materials of collapsed wooden houses when they come close. There were also some cases where the rolling propane cylinders drifted on the water ejecting white smoke of flammable gas with no flame as shown in Fig. 3(c). Kitamura estimated that causes of ignition were sparks from metals which collided each other by tsunami [4].

Some people who remained in wooden houses when the tsunami reached noticed this LP gas cylinder pattern of fires occurred at nearby houses. Some people noticed propane cylinders were drifting, rolling and jetting flame on the water, which caused fires at buildings or pieces of collapsed wooden houses. There are many witnesses of fires in tsunami broken houses who heard a sound of explosion from the house.

Figure 4 shows one case of this LP gas cylinder pattern fire without a direct eyewitness. Mr. Toru Suzuki, a volunteer fire fighter of Otsuchi Town volunteer fire company, took this photograph of Fig. 4(b) at 15:26, 11th March 2011 in Ando District in Otsuchi Town in Iwate Prefecture. This was six minutes after the hit of the tsunami at 15:20 here as shown in Fig. 4(a). The district was covered with sand smoke at 15:20, which means the impact of the tsunami was devastating. The location of Ando District is at the left hand of opposite shore in Fig. 4(a).

When he passed through this point before the hit of tsunami, he did not notice a fire around here. He heard a sound of propane gas cylinder explosion after the hit of tsunami. Then when he again reached this viewpoint, he noticed that the materials of collapsed buildings were burning. There are some possibilities that the fires were caused by gasoline leaked from automobiles or fish boats, but it would have taken some more time for propagation of gasoline fire to building materials. So the cause of this fire may have been leaking propane gas from cylinders. The cylinders may have been pushed into a house and caused explosion inside of the house. This estimation meets the size of the fire in Fig.4(b). The situation of this fire at 16:00 is shown in Fig. 4(c).

(a)  (b)  (c) 

Fig. 3. Liquefied propane gas cylinders at usual situation (a) and tsunami affected situation (b), (c).
(a) Liquefied propane gas cylinders in front of a house at usual situation [8]; (b) Disconnected liquefied propane gas cylinder and buckled at the top by tsunami, Iwate; (c) Combustible gas ejected from a liquefied propane gas cylinder floating on the tsunami waves at a cross street near Yuriage Junior High School around 15:50, 11 March 2011, Natori, Miyagi [9].

(a) around 15:20, 11 March 2011, Otsuchi, Iwate [10]

(b) 15:26, 11 March 2011, Ando, Otsuchi, Iwate [11]

(c) 16:00, 11 March 2011, Ando [11]

Fig. 4. Fire occurrence process, (a) situation at the time of tsunami arrival with sand smoke, (b) a small fire occurred after the tsunami arrival on the tsunami waves, (c) continuously occurred small fires on the flooded area by tsunami.

2.2. Tsunami-induced fire related to leak from automobile fuel tank (Automobile Fuel Tank Pattern)

In many cases of automobile fuel tank pattern fire, a number of automobiles parked in front of a building were washed up by the tsunami and crashed against the building, bursting into flames near the wall of the building.

Figure 5 shows a typical case burning in front of Kadonowaki Elementary School in Ishinomaki City in Miyagi Prefecture. About one hundred automobiles with which local people evacuated to the ground of this elementary school were hit by tsunami at around 15:40 11 March 2011. Because the tsunami waves contained floating houses and materials from broken houses, automobiles were pushed and squeezed between these substances in tsunami waves and the reinforced concrete school building. Fuel tanks and vehicle fuel filler pipes were destroyed when automobiles were swept away by the tsunami smashed against the building. Gasoline leaked and caused fires.

Figure 6 shows another case. After the earthquake, local people came to the ground of this elementary school by automobiles in anticipation of tsunami. There were about thirty to forty automobiles parked in front of the gymnasium. When the tsunami reached here, about ten automobiles were pushed into the gymnasium and seven automobiles were piled up between the gymnasium and the main building. A teacher at the school who had evacuated to a mountain behind the elementary school heard the sound of electric short and explosion from the gymnasium and noticed a smoke coming out of the gymnasium. Local people also heard the sound of explosion a few minutes after the hit of tsunami and noticed that one third of the roof of the gymnasium was blown off as shown in Fig. 6(a). There may have been an explosion of gasoline which leaked from the tanks of the automobiles pushed into the gymnasium by the tsunami. Fig. 6(b) shows inside of the gymnasium after the fire.

(a) 17:25, 11 March 2011, Kadonowaki, Ishinomaki, Miyagi [12].

(b) 21 March 2011 [12].

Fig. 5. A case of automobile fuel tank pattern fire. (a) fire spread to combustible materials and a broken house floated and landed on the Kadonowaki Elementary School ground with tsunami waves; (b) burnt automobiles in front of the elementary school building.

(a) 11 March 2011, Kesen Elementary School, Rikuzentakada, Iwate [13]

(b) 5 June 2011, taken by the author

Fig. 6. A case of automobile fuel tank pattern fire. (a) a roof partially blown off by an explosion in the gymnasium of the Kesen Elementary School few minutes after the hit of tsunami; (b) burnt automobiles inside of the gymnasium of Kesen Elementary School.

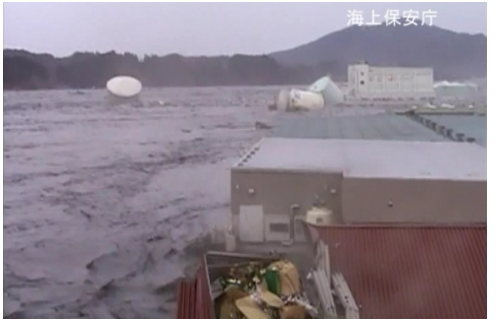
2.3. Tsunami-induced fire related to leak from oil tank (Oil Tank Pattern)

Oil-storage tanks etc. at industrial plants in harbors, ships and fish boats which had been handling flammable liquid were destroyed by the tsunamiand floated on the tsunami waves as shown in Fig 7(a). The leaked oil being absorbed to timber and other materials from collapsed buildings etc. caused fires like wick combustion.

The massive fire at Kesennuma Bay was a typical of this pattern. Oil flowing out of the destroyed oil tanks at Kesennuma Port may have adsorbed to farming rafts and collapsed pieces of wooden houses swept by the tsunami, and was ignited into flames [4, 15]. These blazing objects, covering some of the water surface, drifted from Kesennuma Bay outwards to Oshima Strait to reach the tsunami-flooded coastal area where the fire spread to ships, automobiles, factories, houses and forests. These blazing objects also drifted inwards to Shishiori District where already LP Gas Cylinder pattern fires had broken out just after the tsunami reached as shown in Fig. 7(b). The people who evacuated to tsunami refuge buildings near the pier of Shishiori were surrounded by the fires of these two types until the next morning.

The proportion and rate of occurrence of these three patterns of tsunami induced fires are unknown due to the lack of physical evidence. There are some verbal evidences but they are not yet organized to form the whole picture.

There were also other patterns of fire occurrences related to tsunami other than the above-mentioned three patterns. For example, fires from electrical short fires from batteries of automobiles flooded by sea water [16].



(a) around 16:00, 11 March 2011, Kesennuma, Miyagi [14]

(b) around 18:00, 11 March 2011, Kesennuma, Miyagi [14]

Fig. 7. Fire occurrence process, (a) floating oil tanks from which oil leaked onto the tsunami waves; (b) fire of combustible materials from broken houses which soaked spilt oil floating toward Shishiori District where LP Gas Cylinder pattern fires occurred.

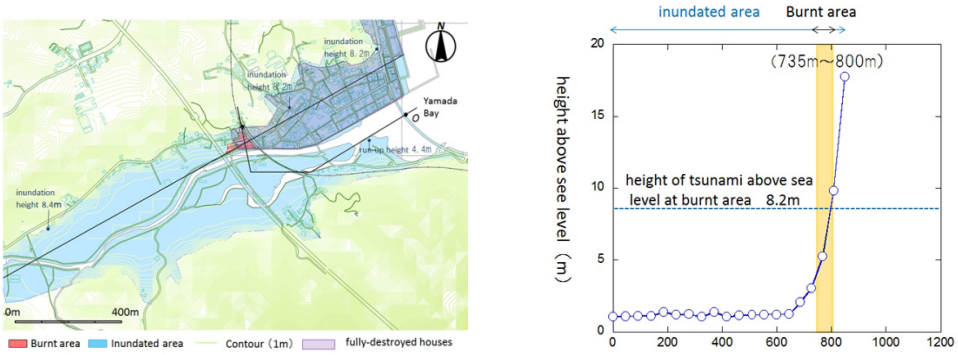


Fig. 8. Fire spread of LP Gas Cylinder pattern fire to broken houses at the edge of tsunami flooded area (Origasa district in Yamada town, Iwate prefecture). Range of burnt area was obtained by on-site reconnaissance with reference satellite image after the tsunami fire.

Fig. 9. Fire spread in Origasa district at 16:07, 11 March 2011 (photograph taken and offered by local people).

3. Fire spread and escalation

Degree of fire spread depends on the distribution of combustible materials. When the tsunami hit wooden housing areas, most of the wooden houses along the seashore were swept away and combustible materials from the broken houses and broken houses themselves accumulated along hillside or in some cases along banks. Some debris from the devastated houses was pulled out in the backwash. The piled combustible materials in such situation caught fire from drifting houses and boats which had been ignited. Some fires broke out at the location of the accumulated debris at hillsides or banks.

Figure 8 shows one case of LP Gas Cylinder pattern fires. A rolling propane cylinder floating on the water with flame jet spread fire to broken buildings in Origasa District in Yamada Town, Iwate prefecture. The depth of the tsunami was about 6 meters at the fire origin of this burnt area. Some buildings were partially destroyed by fire and at the middle height of first floors were burnt, so it seems that the height of flooded water decreased when the burning propane tank reached the site to cause a fire as shown in Fig. 9.

Figure 10 shows a case where there are witnesses that a leaking propane cylinder exploded to ignite a fire after the tsunami hit. Fig.11 shows the fire situation eighteen minutes after the tsunami hit this district. As the height above sea level was about 13 meters, there was no tsunami water in this area at that time. There were wooden houses and fire spread to them. Four local people tried to block fire with a hydraulic shovel and extinguished fire using home hose [1] .

Figures 1, 12 and 13 show fire sites where multiple fires occurred in combustible material beds along a hillslope in the tsunami flooded areas. This means that there is high probability of fire occurrence in this kind of beds and fires tend to spread widely at these beds.

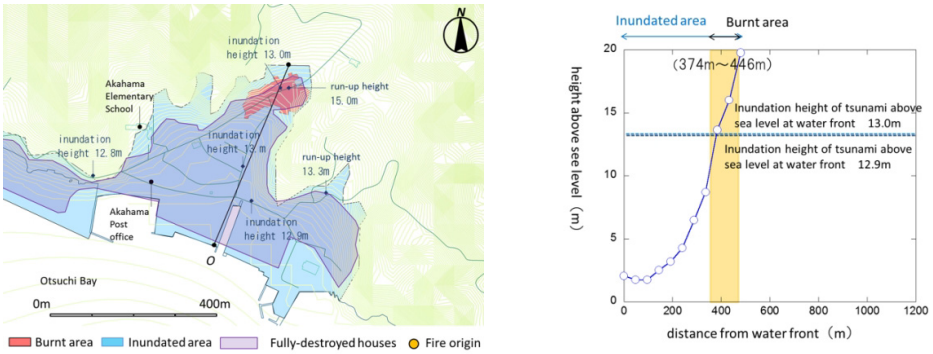


Fig. 10. Fire spread of LP Gas Cylinder pattern to houses at hillslope in a tsunami flooded area (Akahama district in Otsuchi town, Iwate prefecture).

Fig. 11. Fire situation at 15:38 (18 minutes after the hit of the tsunami), 11 March 2011 at Akahama district in Otsuchi town, Iwate prefecture [17].

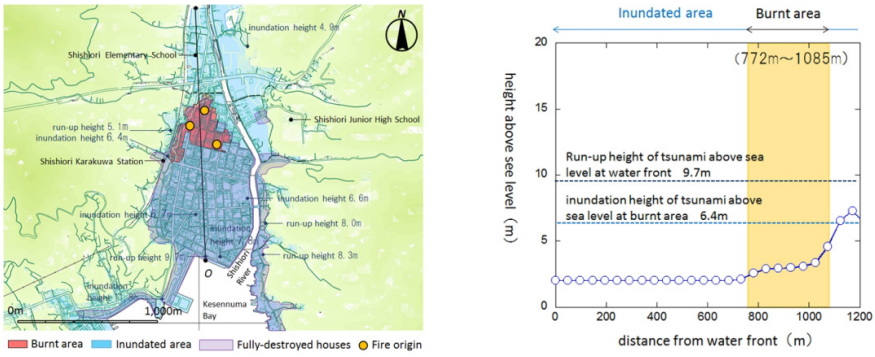


Fig. 12. Spread of fires to houses at slopes in a tsunami flooded area (Shishiori district in Kesennuma city, Miyagi prefecture).

Gradients of the slopes in the fire sites of Figs. 12 and 13 are not so steep compared with other fire sites shown in Figs. 1 and 10. It could be said that the burnt area tends to be wider at a glacis slope. Fig. 14 shows that width of the combustible material bed is wide at this glacis slope.

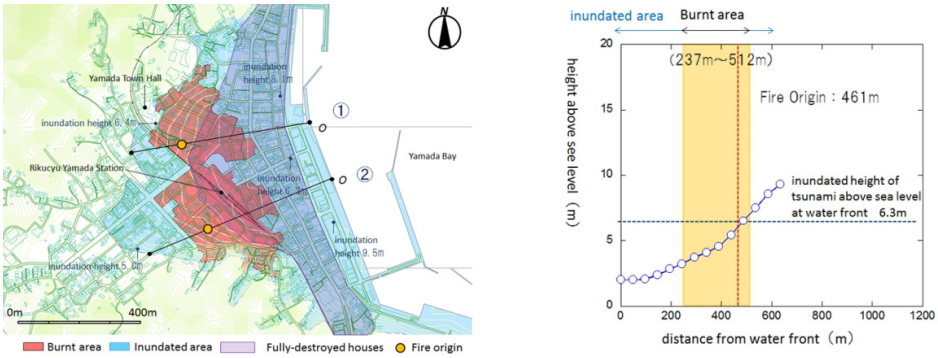


Fig. 13. Spread of fires to houses at slope in a tsunami flooded area (Yamada district in Yamada town, Iwate prefecture).

Fig. 14. Fire situation at 16:15, 11th March 2011, about one hour after the tsunami hit Yamada district in Yamada town [18].

In the pattern in which a fire was triggered by parked automobiles being washed up and smashed against reinforced concrete buildings, automobiles fire spread to building when combustible materials from broken houses and floated and landed woodenhouses existed. When there were scarce combustible materials around automobiles, much of these kind of automobile fire tended not to spread to non-wooden buildings as shown in Fig.15.

(a) 16 March 2011, Miyagino, Sendai, Miyagi [19]

(b) 8 April 2011, Miyagino, Sendai, Miyagi [20]

Fig. 15. Automobile Fires. (a) in front of Yume Messe Miyagi; (b) in front of a warehouse where 280 automobiles swept away by the tsunami from a parking lot and landed here to ignite.

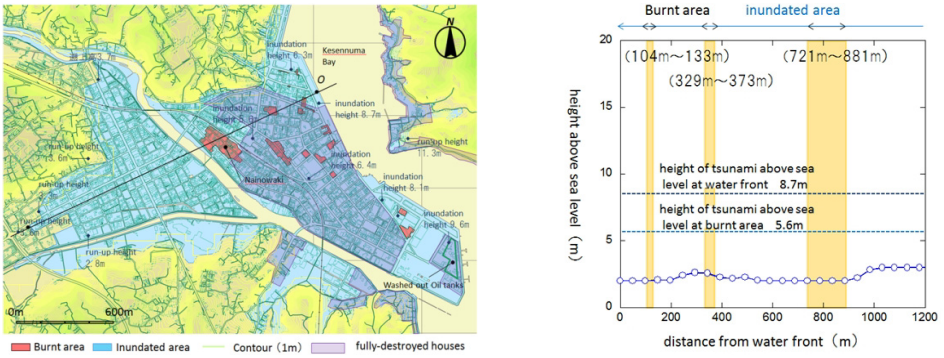


Fig. 16. Fire site of mainly spread fires from leaked oil tank patternfires in a harbor district (Kesennuma city, Miyagi prefecture).

Fig. 17. Combustible material beds surrounded with red line in a harbor district on 12th March 2011, The rightmost area caught fire on 14th March 2011 by unknown process (Kesennuma city, Miyagi prefecture) [21].

In the pattern in which fires were initiated by hazardous material leaked out of oil tanks, drifting objects in flames reached the coastal areas flooded by the tsunami, resulting in fires spreading to nearby buildings and other objects in the vicinity of the coastal and wharf areas.

In Fig. 16, most of the burnt areas were spread by typical leaked oil fires pattern. Because wooden building around these burnt areas and combustible materials were almost swept away as shown in Fig. 17, the spread of fire were limited to remaining buildings and fire area did not became large.

Some of the small fires and the largest fire were not related to leaked oil. In some small burnt areas fires occurred at factories. Hazardous materials which had been used in the factories seem to have been ignited when hit by the tsunami. Because the factories were not wooden structure, the buildings were not swept away by the tsunami, so the fires spread only inside of the factory buildings. In the biggest burnt area near Minami Kesennuma Station a fire occurred on 14th March 2011 by unknown reason.

This area before the fire is shown in Fig. 17. In the rightmost area there was a bed of combustible materials formed by the tsunami. Maybe because the depth of the water the tsunami brought was shallow around here or maybe by chance, the drifting fires did not reach the combustible materials bed here. As the land is flat as shown in Fig. 16, the combustible bed was shaped like a pyramid, on the top of that was a robust building. If the condition of the tidal wave had been different, the combustible materials could have caught fire from drifting fire, leading to a spread of fire to wider area.

Figure 18 shows one example of fire spread in a flat area. Burnt area depended on distributions of combustible materials and areas with densely built up wooden housing. There was a variety in distributions of combustible materials from wooden houses collapsed in the tsunami, depending on the density of housing, and with or without open spaces and obstacles like railroad and highway banks. In this case burnt areas in flat area were limited.

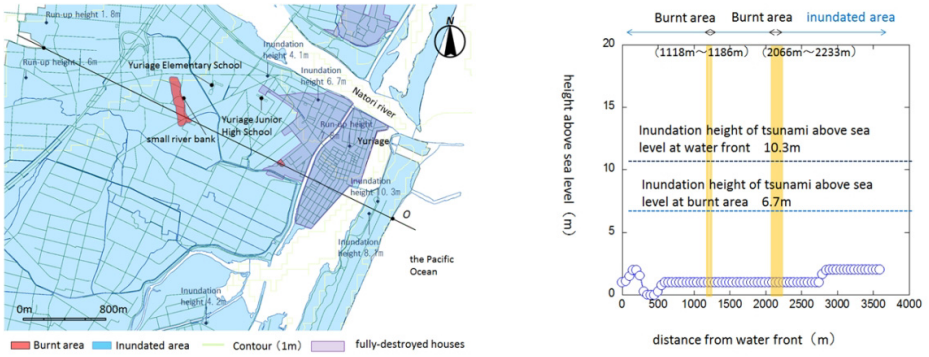


Fig. 18. Fire site in flat area (Yuriage district in Natori city, Miyagi prefecture).

Table 2. Distribution of Fire Spread Area of Urban Fires occurred around boundary line of Flooding Areas from Tsunami

Prefecture	Municipality	10～20ha	5～10ha	1～5ha	0.3～1ha	0.01～0.3ha
	Noda Village					1
	Miyako City				1	
	Yamada Town	1			4	1
Iwate	Otsuchi Town		1	2	3	
	Oofunato City				2	
	Rikuzentakada City					1
	Kesennuma City		1	1		
	Minamisanriku Town			1		
	Ishinomaki City		1		1	1
Miyagi	Sendai City				2	1
	Natori City			1		
	Watari Town					2
Fukushima	Soma City					1
	Iwaki City			1		
Total		1	3	6	12	8

* Only spread fires are included. There were many unidentified small fires.

Table 2 shows burnt areas of major fires. The total burned area was approximately 65 ha (hectare), excluding the extensive area of burned forests.

4. Status of response and secondary evacuation

There are some hearing investigations on people who responded to and evacuated from tsunami fires [1]. There are also some experiences indicated in books and internet web sites. From these experiences, the tendency of response to tsunami fires and secondary evacuation is as following.

4.1. Secondary evacuation from two story wooden houses

There were some people whose tsunami evacuationwas delayed and left behind in the second story of wooden houses. When they survived and noticed the fire approaching, they tried to claw their way out of the house to evacuation buildings or hillsidenearby between tsunami waves through rough route with rubbles.Local people and some volunteer firefighters helped secondary evacuee to climb up the hillside near Kadonowaki Elementary School as shown in Fig. 1 (b) and Fig. 19.

After the emergency, many burnt bodies were found where the depth of tsunami wave was below the second floor level in Ootsuchi Town as shown in Fig.1 (a). In this case, it could be estimated that those people had been lost their lives in the

fire. In Shishiori District in Kesennuma City where at least three LP Gas or automobile pattern fires occurred just after the arrival of tsunami, many burnt bodies were found. Near Kadonowaki Elementary School, 55 burnt bodies were found [22].

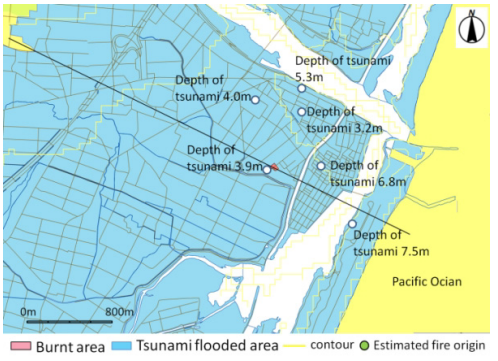
Fig. 19. Location of rescue from 2 story houses in fire risk, 15:53, 11 March 2011 (Kadonowaki, Ishinomaki, Miyagi) [23].

4.2. Secondary evacuation from tsunami refuge buildings

In the case where people were evacuated to designated tsunami refuge buildings or nearby buildings, the evacuees had to be evacuated once again when fires occurred and the buildings became in danger. Secondary evacuation was very difficult in the circumstances where the area was submerged in tsunami water. People had to evacuate between tsunami waves or through rough route with rubble.Weak persons had to hide in a safe fire compartment in the building and their supporters tried to fight against the fire.

Figure 20(a) shows designated tsunami refuge buildings in Kesennuma City. Green circles with white space inside indicate the locations of refuge buildings where evacuated people saved their lives. Green filled circles indicate locations of refuge buildings with no usage experience. Inundated area is indicated by blue dotted lines and burnt area by tsunami fires are indicated by red. Although people saved their lives in the tsunami refuge buildings, there were fire spread risk because there were some combustible materials between the buildings and the fire area. In some cases, the flame spread to the buildings.

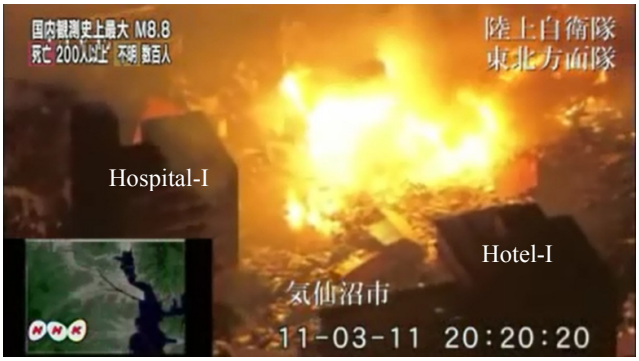
Figure 20(b) shows one example of these cases. There were about 30 aged persons and about 10 staffs in the nursing home. Staffs helped aged persons to escape to third floor before the tsunami arrival. After a meanwhile a fire ignited and spread to north side of the building. Because there were some space between the street and the building and the amount of combustible materials were few, the fire did not spread to the building. Then the fire came from south side. There were some broken houses which were floated by tsunami waves and landed in front of the east side of the building with small space. The fire spread to some resident rooms along the east side. The aged persons and staff escaped from some rooms on the third floor to one resident room on the same flooralong the west side where the influence of the fire was minimum, still inside of the room was hot like summertime.



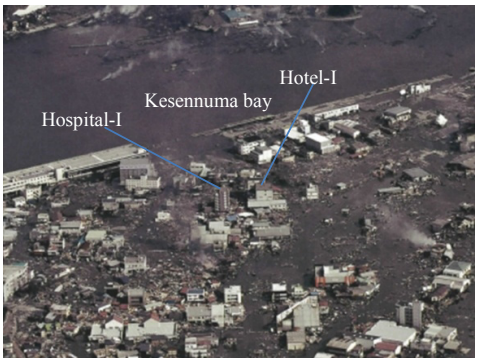
(a) Location of tsunami refuge buildings, Kesennuma, Miyagi

(b) Nursing home, Shishiori, Kesennuma, Miyagi

Fig. 20. Tsunami refuge buildings (a) locationin Kesennuma city, Miyagi prefecture. (b) one example of tsunami refuge buildings where tsunami fire spread to some part of the building.



(a) 20:20 11 March 2011, Kesennuma, Miyagi [24]



(b) 12 March 2011, Kesennuma, Miyagi [21]

Fig. 21. Tsunami refuge buildings. (a) in fire risk; (b) the day after the earthquake.

(a) Kadonowaki, Ishinomaki, Miyagi

(b) Backside of the building [25]

Fig. 22. Tsunami refuge building. (a) burnt tsunami refuge building by hillside. (b) a platform for bridge at the backside of the elementally school.

Figure 21(a) shows tsunami refuge buildings in Bentencho, Kesennuma City. About seventy local people including twenty vulnerable aged persons evacuated to Hotel-I before the tsunami arrival. There were five staffs in the hotel. In the evening of 11 March 2011, a fire broke out in the vicinity of the hotel as a result of fire spread from oil tank pattern fire from the kesennuma bay. Around 21:00 the fire spread to a building next but one to the hotel as shown in Fig. 17 and Fig. 21(a). The staff considered secondary evacuation but it was almost impossible to evacuate the building because of twenty vulnerable aged persons who could not walk themselves. So, they tried to seek rescue and prepared for fire fighting with indoor fire hydrant. Finally the fire did not spread to the hotel and local people in the hotel were rescued by a helicopter of Tokyo Fire Department in the afternoon of 13 March. Patients including infants were also rescued from Hospital-I next to the hotel at that time.

In Ishinomaki City, an elementary school was functioned as a tsunami refuge building, but when the tsunami came here, automobile pattern fires occurred as shown in Fig. 5. About 50 local people helped each other to escape from this building up to the hillside as shown in Fig. 22(a). As there was a gap between the building and the hillside, they throw a bridge using a platform over the gap to get out of the building as shown in Fig. 22(b). This secondary evacuation was taken place in emergency situation with fire and smoke inside of the building.

In Miyagino Ku, Sendai City, There were 537 evacuees at Nakano Elementary School. At about 200 meters west side of the school, about ten buildings, combustible materials from broken wooden buildings and about 50 automobiles got fire and spread in the direction of the school with strong west winds. Fire-fighting operation with helicopters was done in success.

(a) 12 March 2011, Miyagino, Sendai [26] (b) 11 March 2011, Nakano Elementary School, Miyagino, Sendai [26]

Fig. 23. Tsunami refuge building in fire risk. (a) location of elementary school and the fire; (b) elementary school with a lot of combustible materials.

5. Conclusions

Hazardous materials were the main factor for occurrence of tsunami fires. Combustible materials from houses broken by tsunami determined the possibility for the fire to spread. Amount of combustible materials are related to number of coastal wooden housings. Drifting materials, houses and boats also contributed to fire spread.

It is difficult to evacuate from a tsunami refuge building or a collapsed house in case of fire, it is necessary to consider secondary evacuation routes, safe zones in the building, fire extinguishing equipment and other strategies. It is also important to consider the possibility of secondary evacuation in case of tsunami fires for emergency evacuation plan against tsunami.

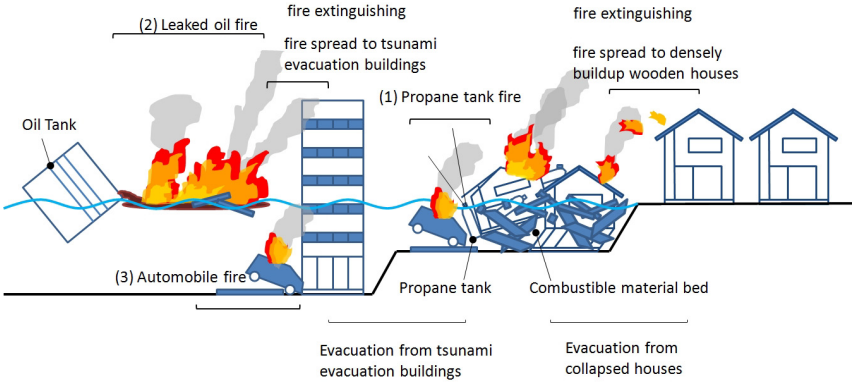


Fig. 24. Mechanism of tsunami fire and responses [27].

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References

[1] A Preliminary Report of Investigation on Earthquake and Tsunami Fires, JAFSE (Japan Association for Fire Science and Engineering), Nov. 2011. (in Japanese)

[2] Sekizawa, A., Sasaki, K. 2012. "Overview of Fires Following the 2011 Great East-Japan Earthquake; Analysis of Fire Data based on the Questionnaire Survey to Fire Brigades in Affected Regions," Proceedings of JAFSE Annual Symposium 2012, Japan Association for Fire Science and Engineering, pp.112-115. (in Japanese)
[3] Geospatial Information Authority of Japan: Inundated Area by Land Use (Interim Report), Mar. 2011. (in Japanese)
[4] Kitamura, Y., 2012. "Consideration to the Tsunami Fire in KesennumaCity," Proceedings of a Research Workshop on Fire Safety, Architectural Institute of Japan. (in Japanese)
[5] kurou199, 2011. "Tsunami observed from Yuriage Junior High School," http://www.youtube.com/user/kurou199. (existed on 7 July 2012)
[6] Photograph Offered by a Local People Who Evacuated to a Hillside, 2011.
[7] Report of a Survey for Sustainable Supply of LPG as Considering the Situation of the Great East Japan Earthquake, Mizuho Information & Research Institute, Inc.,Feb. 2012. (in Japanese)
[8] Response of LP Gas Industry for the Great East Japan Earthquake and Proposal, Japan LP Gas Association, Nov. 2011. (in Japanese)
[9] nworldt, 2011. "Tsunami inYuriage," http://www.youtube.com/user/nworldt. (existed on 7 July 2012)
[10] Akihiro Sato, 2011. "The moment of the tsunami at Otsuchi-cho in Iwate," http://www.project-next.com/projectNext/Message.html. (existed on 7 July 2012)
[11] Toru Suzuki, 2011.A Photograph Offered by Toru Suzuki.
[12] pzj*77*200*, 2011. East Japan Earthquake Picture Project, http://archive.shinsai.yahoo.co.jp/. (existed on 7 July 2012).
[13] Local person, 2011. A Photograph Offered by a Teacher of the Kesen Elementary School.
[14] Japan Coast Guard, 2011. Video offered by Japan Coast Guard.
[15] Shinohara, M. et al., 2012. "Fires in Kesennuma Following the 2011 Great East Japan Earthquake," Proceedings of JAFSE Annual Symposium 2012, Japan Association for Fire Science and Engineering, pp. 22-23. (in Japanese)
[16] Hagimoto, Y., 2011. "Ignition pattern," A Preliminary Report of Investigation on Earthquake and Tsunami Fires, Japan Association for Fire Science and Engineering. (in Japanese)
[17] JMSDF (Japan Maritime Self-Defense Force), 2011. "Airborne Imagery over Iwate Prefecture by JMSDF just after the Earthquake," http://www.jiji.com/jc/movie?p=top225-movie02&s=243. (existed on 7 July 2012)
[18] JGSDF (Japan Ground Self-Defense Force), 2011. "The Aftermath of the Tsunami Caused by the Tohoku Region Major Earthquake Off the Pacific Coastline. 2011 March 11th approximately 4:15 p.m. Taken from the Air above Yamadamachi Town and Ohtsuchichou Town in Iwate Prefecture." http://www.youtube.com/user/KohoHachinohe. (existed on 7 July 2012)
[19] Jin, 2011. East Japan Earthquake Picture Project, http://archive.shinsai.yahoo.co.jp/. (existed on 7 July 2012)
[20] Hagiwara, I., 2011. "Fire Situation in Miyagino-ku, Sendai-City," A Preliminary Report of Investigation on Earthquake and Tsunami Fires, Japan Association for Fire Science and Engineering. (in Japanese)
[21] Bon Ishikawa, 2011. "THE DAYS AFTER: Memories of the Great East Earthquake", a photography book, Asukashinsya.
[22] Yomiuri, S., 11 January 2012. "Problem of Tsunami Fire". (in Japanese)
[23] Cocoxom, 2011. http://www.youtube.com/watch?v=RLgP3nmpaRc. (existed on 7 July 2012)
[24] NHK. 2011. http://www.youtube.com/watch?v=bdmvCydsjC4. (existed on 7 July 2012)
[25] Nijiirocrayon, 2011. http://kodomohinanjoclub.cocolog-nifty.com/blog/2011/07/post-3842.html. (existed on 7 July 2012)
[26] Activities of Sendai Fire Department against the Great East Japan Earthquake, Sendai Fire Department, 2011. (in Japanese)
[27] Hokugo, A., Nishino, T., Inada, T., 2012. "Damage and Effects Caused by Tsunami Fires: Fire Spread, Fire Fighting and Evacuation," Proceedings of the International Symposium on Engineering Lessons Learned fromthe 2011 Great East Japan Earthquake. Tokyo, Japan, pp.43-62.