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Numerical analysis of tsunami-triggered oil spill from industrial parks in Osaka Bay

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ABSTRACT

Oil storage tanks in industrial parks were heavily damaged by a large-scale tsunami, and large-scale oil spill occurred, which led to a fire. Moreover, it was found that mud samples in these regions had a high level of oil contamination after the disaster, showing that the tsunami triggered high turbid water mixed with spill oil and deposited on the sea bottom. For industrial zones around the coastal line with the potential for tsunamis, the building of a scenario of a tsunami-triggered oil spill from these industrial parks is urgently needed for planning the ship evacuating routes and the evacuation of residences nearby. This was carried out by numerical simulations of two-phase flow around the industrial parks. The results could build a scenario of a tsunami-triggered oil spill from industrial zones and could help to add the oil spill effect in reviewing the risk management of industrial zones around the coastal line.

1. Introduction

1.1. Background

On Friday 11 March 2011 at 05:46:23 UTC, the Great East Japan Earthquake with a magnitude of 9.0 Mw occurred approximately 70 km east of the Oshika Peninsula of Tohoku region, Japan. An approximately 180-km-wide seabed at 60 m offshore from the east coast of Tohoku was elevated by 10 m. This seabed elevation triggered a major tsunami, which resulted in tremendous devastation along the Pacific coastline of Japan's northern islands. The recorded tsunami observations following the earthquake along the coastline stated that most severe cases, corresponding to wave heights of above 7 m, occurred in Iwate, Miyagi and Fukushima prefectures located in the northeast part of the Japan mainland.

Meanwhile, in the Kesennuma Bay in the Miyagi Prefecture, the waves were measured to have a height of 9 m followed by maximum tsunami outflow currents with a speed of 11 m/s less than 10 min after the wave head. Kesennuma City stated that 22 out of 23 oil tanks (with a capacity of 40–3000 kL), were destroyed by the tsunami in the Mianmi Kesennuma District, and 11,543 kL of petroleum oil, mainly heavy oil as well as light oil and gasoline, was estimated to be spilled out.

1.2. Damage from fire and residual oil contamination

The Kesennuma Bay area was changed into a sea of fire during the Great East Japan Earthquake. The tanks, which were destroyed by the tsunami, were originally located at the entrance of the bay to fuel fishing boats. When the tsunami hit those oil tanks, most of them broke and drifted into the bay along with spilled oil. According to the fire department of Kesennuma City, 18 tanks were found scattered in all parts of the city, however, four tanks were missing. The farthest drifted tank was found moved about 2.4 km into the mouth of the Bay. The major spillage of heavy oil strengthened the fire. When the seawater and oil mixture came in contact with some heat source (perhaps, short-circuiting of wrecked fishing boat or cables), there was a start of ignition, and the fire finally reached back to the city itself. In Kesennuma City, 13 cases of fire occurred after the tsunami during the Great East Japan Earthquake.

Usually, grade A heavy oil that spills onto the surface of the sea has a low probability of inflammation and rapid volatilization. However, when the wood pieces among the debris of broken buildings and port structures absorbed the grade A heavy oil, they became a good source of burning. Moreover, the small pieces of oil-soaked wood fire scattered around acted as candle wicks and kept the fire going for a long time. At the same time, they were dispersed

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by the wind and tsunami and created a great fire, which even spread to the isolated island of Oshima.

According to the publication of the analysis, research and information on accidents (ARIA) database operated by the French Ministry of Ecology, Sustainable Development and Energy (2013), the fishing port was covered with 5 cm thick precipitation layer of oil. In addition, NHE (*n*-hexane extract) from the seabed with the thickness of 10 cm was measured, assuming that the distribution is uniform within the thickness (Arakawa and Nakamura, 2016). The time history of the amount of NHE in Kesennuma Bay was determined, and it revealed that the level of NHE reached 24% of total spilled oil in December 2012, with the level decreasing to 11% in December 2015.

After burning out a large extent of spilled out oil on the sea, some of the left-over oil seems to have been carried away by the tide and wind, but there are still chances of those drifting oil contaminations approaching nearby coast again. Moreover, it has been found that the mud sample in the Kesennuma bay has a high level of oil contamination. Usually, oil is considered to be lighter than seawater and the oil spill never sinks down to the sea bottom. However, in a tsunami-triggered oil spill, the tsunami triggered high turbid seawater mixed with the oil spill out. This mixture of mud and oil might have settled to the sea bottom.

The Mainichi Newspaper (2012) reported that, from July 2011 to February 2012, surveys were carried out in 71 places of 30–40 m depth seabed, and all the mud sediment samples were observed to include oil deposits, which is difficult to decompose the mud sediment into mud itself and oil. Among them, 10 survey points close to the land have 1.9 to 1.1 times higher oil contamination level than the national environmental standards (1000 ppm). Though any further oil contamination has not been detected in the seawater of Kesennuma Bay, in the future, the effect of oil contamination in the mud on the aquaculture of seafood needs to be considered.

1.3. Analysis and countermeasures

Before the Great East Japan Earthquake, the potential risk of destruction of oil storage tanks in coastal industrial zones by tsunami waves was identified, but any countermeasures were not taken for this case. The Fire and Disaster Management Agency, according to Kahoku Shimpo Publishing Co (2014), analyzed the relationship between the depth of inundation and extent of damage to fuel tanks in both Iwate and Miyagi Prefectures after the disaster at the Great East Japan Earthquake. It was found that if the height of the tsunami inundation is between 2.5 and 5 m, the pipes start to burst, and when the inundation rises above 5 m, the main body of the tank suffers damage as well. The tsunami fire of Kesennuma Bay revealed the disaster risks that lie in coastal industrial zones, where fuel tanks are concentrated. The Agency instructed 33 prefecture-owned petrochemical complexes to review their disaster prevention plans.

1.4. Risk analysis in Osaka bay

In Osaka Bay, there is an intensive distribution of industrial parks along the coastline. In particular, Northern Osaka Port and Sakai Senboku Industrial zones comprise a massive number of oil storage tanks. In addition, there is a potential Nankai Trough earthquake of an intensity of 6 or smaller. This earthquake can unleash a tsunami with a maximum wave height of 6 m along the coastline of Osaka Bay. To review the risk assessment of the Osaka Bay Area, building the scenario of a tsunami-triggered oil spill from these industrial parks is urgently needed for planning the ship evacuating routes from the bay and the evacuation of nearby residences. Hence, this research proposes to estimate the distribution of potential oil spill in the Osaka Bay caused by a tsunami due to a Nankai Trough earthquake by numerical simulations. The simulation domains include the residential zones and bay area near the Sakai Senboku Industrial zone in order that the risk analysis of Osaka Bay Area can be revised by considering the effect of oil.

2. Method

2.1. Preliminary analysis of potential oil spill

In Osaka Bay, there were two specific oil storage tank concentration areas: Northern Osaka Port and Sakai Senboku industrial park as shown in Fig. 1. In 2014, Osaka Prefecture Petrochemical Disaster Prevention Cabinet Headquarters (2014) reported the estimated amount of potential oil spill according to tsunami inundation into the industrial parks and oil storage area.

Table 1 summarizes the Headquarters' report. The oil tanks are

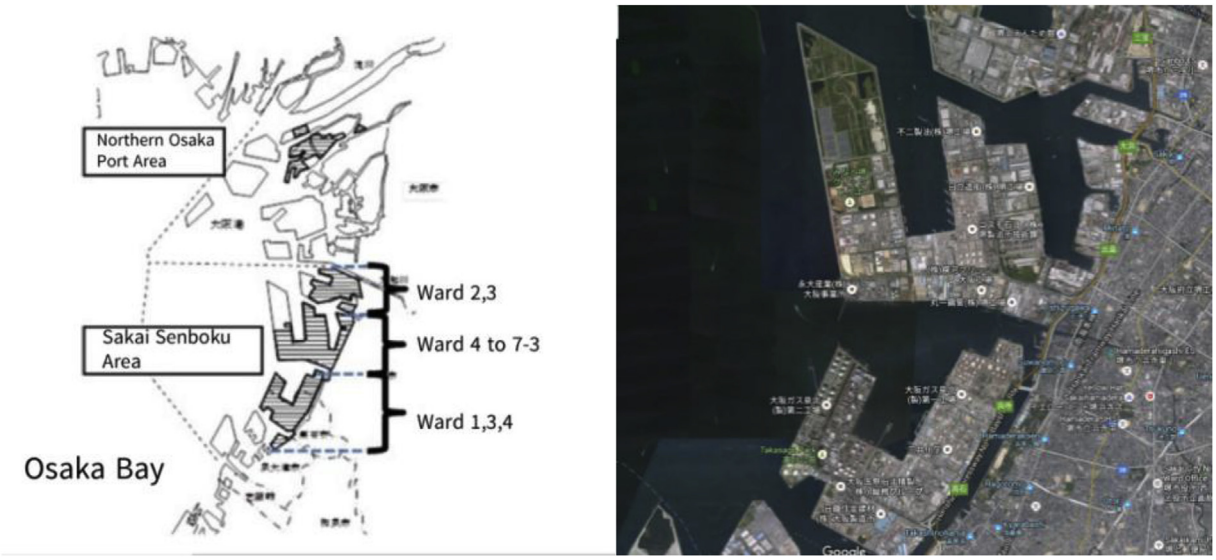

Fig. 1. Industrial zones in Osaka Bay and Sakai Senboku Industrial zones.

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