Cascading Effects of Natural Hazards: Lessons from Recent Natech Accidents and Practices

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A B S T R A C T

Recent trends of disaster present that disasters are more uncertain and complex with unpredictable cascading effects owing to global environmental and climate change. As one of the significant phenomena, natural hazards triggering technological accidents, so-called Natech, which cause acute and prolonged terrifying consequences, have also been increased. Considering low probability but high consequences, Natech accidents often exceed the capacity of disaster preparedness and response. As a result, the need to better manage Natech risks has become a challenge in disaster risk management among all stakeholders, including government, disaster and safety experts, industry, and citizens. Although there have been numerous efforts undertaken by international organizations and individual countries to reduce Natech risks, there are still not sufficient reflections in South Korea. Thus, this study highlights some lessons from Natech risk reduction practices undertaken by individual countries and recent minor Natech cases.

Key words: Natural hazard; technological accident; Natech; cascading disaster; cascading effect, risk management practice

1. Introduction

Recent disaster trends present that disasters are more uncertain, complex, and unpredictable due to global climate changes, industrialization, and urbanization on the blurred territories. It is well known that primary natural hazards can trigger secondary disasters such as fire, explosion, hazardous material releases, and oil spills. These secondary disasters are defined as Natechs, natural hazard triggering technological accidents(Showalter & Myers, 1994; Cruz, *et. al.*, 2004).

Unlike natural hazards, Natech accidents are considered low probability but unexpected consequences(Masys, *et. al.*, 2014) and cascade effects(Kadri, *et. al.*, 2014). Moreover, the cascading effects of Natech accidents occasionally overwhelm the coping capacity of local and central governments in affected areas, and international societies and relevant stakeholders suffer negative impacts of the potential propagation in response and recovery(Steinberg, *et. al.*, 2008). Due to these reasons, risk management based on risk analysis is essential to reduce the conjoint natural and technological hazards and risks.

There have raised international concerns about the risk posed by the conjoint natural and technological hazards and disasters since the 2005 United Nations World Conference on Disaster Risk Reduction. Despite global efforts to reduce Natech, there is still not sufficient consideration and reflection of this concern in South Korea(Park & Cruz, 2022). Thus, this study aims to review recent minor Natech accidents and discuss practices of Natech risk management in the United States (US), the European Union (EU), and Japan. In addition, this study highlights some gaps in the current regulatory system in South Korea.

2. Recent Natech accidents

Natech events can occur in any country whenever natural and technological hazards and risks co-exist. The number of reported Natech accidents over two decades has been consistently increasing (Sengul, *et. al.*, 2012; Suarez-Paba, *et. al.*, 2019), and it may be expected to continue due to climate change (EM-DAT, 2020). Most notable cases of Natechs are mostly major disasters, but there is a number of reported minor Natech accidents. This section introduces some minor cases that recently occurred in Japan and South Korea.

2.1. An explosion at an aluminum recycling plant by floods in 2018

In July 2018, extreme rainfall, approximately 900-1500 mm, poured down and resulted in numerous landslides, river overflows, and floods across southwestern Japan from June 28 to July 8 (Japan Meteorological Agency(JMA), 2018). Due to this heavy rainfall, there were 237 deaths, 8 missing, and 4072 refugees who had to evacuate to emergency shelters(Cabinet Office, 2019). During this period, there was an explosion at an aluminum recycling plant in Shimobara District of Soja city, Okayama Prefecture. The plant was located on a bank between the west side of the Takahashi River and the east side of the Shinpon river, and the north side of the Oda River, where downstream of the former two rivers join. Thus, the district and the recycling plant were exposed to floods.

On July 6, the heavy rainfall violently continued in the district. Although the plant tried to remove melted aluminum from its furnace, it was not successful. Moreover, due to the overflowed river water, the plant was gradually inundated and eventually exploded due to a chemical reaction between remained molten aluminum and floodwater(Fig. 1). Fortunately, there were no fatalities, but some mild injuries and physical damages were reported.

(source: Aluminum plant safety)

Fig. 1. Exploded aluminum recycling plant

2.2. An oil spill at an ironworks factory by floods in 2019

From 26 to August 28, 2019, complicated weather conditions caused unexpected heavy rainfall, recording roughly 600 mm across the Kyushu region, including Saga Prefecture, in Japan(Cabinet Office, 2020). Due to the heavy rain, the government issued special heavy rain warnings and evacuation advisories in wide areas of the region. The southeast area of Saga Prefecture is surrounded by the Ariake sea and consists of plain fields. Two major rivers, Rokkaku and Ushizu Rivers, with several river streams across the fields. Moreover, the area along the Ariake coastlines was reclaimed several centuries ago, and currently, 60% of the area is located on an inland water area(Shimoyama & Nishida, 1999). Due to these reasons, the area has been more exposed to flood risks than other areas and has faced extreme floods over the last several decades (MLIT, 2019).

Despite the vulnerability of this region, an ironworks factory that manufactures components for automotive and agricultural equipment was located 100 m away from the embankments of the Rokkaku River. The manufacturing process of the factory includes heat treatment using a large quantity of quenching oils; thus, approximately 100,000 L of oil was stored below the ground(Saga Shimbun, 2019a). Since this factory had already experienced oil spills caused by severe floods in 1990, they equipped preventive devices involving drainage pumps and flood shutters for oil tanks. However, precipitation of the 2019 heavy rain was enough to exceed the estimated level of floods. A wide area of the region and the factory was flooded and the depth inside the factory building was approximately 60 cm during the event, the early morning of August 28.

As a result, about 54,000 L among 113,000 L of the stored quenching oils spilled from the tanks of the ironworks factory. With rising floodwaters, the spilled oil spread quickly and covered about 980,000 m^2(Saga Shimbun, 2019c), as shown in Fig. 2. Approximately 100 houses were contaminated, and local stakeholders had to clean up the oils until mid-September with support from NGOs, external volunteers, and the Self Defense Force members(Japan Nikkei Shimbun, 2019).

(source: Sankei News, 2019)

Fig. 2. An oil spill from the ironworks factory during the 2019 heavy rain and flooding

2.3. A vapor explosion and fire at a carbon manufacturing plant by flooding in 2020

The 2020 heavy rainfall affected across the Kyushu region to East Japan from 3-31 July 2020. In particular, record-breaking heavy rainfall hit Kumamoto Prefecture and the southern Kyushu region. During the night between 3 and 4 July, hourly precipitation was observed with about 110-120 mm in Kumamoto Prefecture(JMA, 2020). The rainfall events caused the overflow of rivers and a series of floods in the wide area of the Kumamoto region. During the heavy rain and floods, 18 people were confirmed dead, and 24 people were reported missing(JMA Kumamoto, 2020). In addition, due to the flooding, a vapor explosion and fires occurred at a carbon manufacturing plant in Ashikita District, located in the southern area of Kumamoto.

Geographically, the west side of the Ashikita District is well-known as a rias coast (Kumamoto University, 2021). Thus, the district is more vulnerable to flood hazards during the rainy season than other areas. The Carbon manufacturing plant was built on the coastline, which was reclaimed several decades ago, and several river streams are met. The main operation of the carbon plant uses three graphitization furnaces rising to 3000 ℃ by electric energy. Due to this reason, the prefectural and town government equipped a total of 5 drainage pumps in 1932 in order to mitigate flood risks. However, the plant was inundated during the 1982 flood and has equipped with flood protection barriers at the main gate.

The heavy downpour that started during the night of July 3 continued until the following day. Eventually, Ashikita District was broadly submerged and blocked most roads to evacuate and respond. According to available information, the deepest flood depth was reported at about 2 m in the district. Considering the flood, the plant shut down its operation using the graphitization furnaces and protected the facilities with flood barriers at 4 am July 4. However, the equipment could not cover the infiltration of groundwater that was not able to discharge due to floods. As a result, a large amount of steam was spurting out and connected vapor explosions of a furnace and a large fire(Tokai carbon, 2020), as shown in Fig. 3. Moreover, as aforementioned, there were no adequate routes to access the plant; thus, a quick response by the local fire department was delayed.

(source: Nishinippon Shinbun, 2020)

Fig. 3. The carbon manufacturing plant, Ashikita District on July 4, 2020

2.4. Explosions of an underground oil storage tank by a wildfire in 2018

On October 7, 2018, a grassland fire(wildfire) triggered explosions in a gasoline storage tank containing 4,400,000 L (storage capacity: 4,900,000 L) in Goyang, South Korea(Kern & Krausmann, 2020), as shown in fig. 4. The fire was caused by a sky lantern that a man flew carelessly near the gasoline facility and reached the oil terminal within several minutes. The fire was continued for over 17 hours with severe toxic gas and smoke releases. This event was observed at a distance of about 13 Km. Since there are residential areas within 5 Km to the north of the terminal, citizens were limited to open doors and windows to reduce exposure to toxic gases for 3 days. Moreover, this accident caused a huge economic loss an estimated USD 3.33 million.

(source: The Jungang)

Fig. 4. An oil tank exploded at a storage terminal

3. Practices of Natech Risk Management

Many industrialized countries have taken safety measures to prevent chemical accidents and protect industry facilities and infrastructure. However, specific consideration for the conjoint natural and technological disasters in traditional risk and emergency management has been underestimated. With increasing the number of Natech accidents and Natech risks, there have been gradually advanced efforts to reduce Natech risks, and establishing Natech-specific legislation is an ongoing project in several countries. This section summarizes regulatory requirements in risk and emergency management for Natech accidents in the United States, the European Union, and Japan.

3.1. The United States

The Risk Management Plan (RMP) rule introduced by The US Environmental Protection Agency (EPA) in 1996 requires industrial facilities to develop risk and emergency management plans to protect the public from accidental hazardous material releases(US EPA, n.d.). The RMP rule requires the implementation of a risk management plan, including risk assessment, prevention program, and emergency response program, and the dissemination of adequate information regarding chemical risks to local stakeholders. However, the rule does not specifically consider natural hazards as external hazards that could trigger chemical accidents(Park and Cruz, 2022). In addition, other federal regulations also do not address the potential hazardous material releases by natural hazards, cascading effects of natural hazards, and the need for reducing Natech risks(Cruz, 2005).

The state of California has developed the California Accidental Release Prevention (CalARP) program to implement specific risk management related to a Federal Regulated Substance due to earthquake hazards. The CalARP program aims to mitigate the risks of accidental hazardous material releases that could damage public health and the environment during earthquakes (Park and Cruz, 2022). The program mentions risk information disclosure can mitigate the releases of chemicals and the intensity. Thus, according to the Right-to-Know Act, the program highlights that individual chemical firms should provide the results of risk management and appropriate risk information to the public (Park, 2020). However, the CalARP program still has no provision for cascading effects of natural hazards and land use planning.

3.2. The European Union

The European Union established the Seveso Directive in 1982 to control significant chemical accident hazards that pose a threat to the public(EU 1982). The Directive highlighted the necessity of risk communication, that must support effective risk management between key stakeholders, such as governments, industry, relevant organizations, and the public. The Seveso II Directive, in 1996, was then issued, referring to lessons from past chemical accidents(EU 1996). As with regulations of the United States, the Seveso II requires individual industries to disclose hazardous material information, including storage conditions and potential impacts on neighboring communities, adequate prevention measures for chemical accidents, and emergency plans in order to mitigate chemical accident risks and potential consequences. In 2012, the European Union issued the Seveso III Directive considering advanced hazardous material classifications and public risk awareness. Notably, Directive III involved more detailed requirements to consider external hazards such as earthquakes or floods in risk assessment(EU 2012). Furthermore, unlike regulations of the United States regulations, the Seveso Directives explicitly point out the need for the analysis of potential cascading effects and land use and other relevant policies to residential areas and surrounding environments.

3.3. Japan

The 2011 Great Japan Earthquake and tsunami that resulted in several chemical accidents, the nuclear powerplant explosion, and the destruction of social and industrial infrastructure have changed the perspective on Natech accidents in Japan and the international community. Due to these catastrophic cascading disasters, the Japanese government has initiated improving regulatory requirements to reduce natural and technological hazards and risks.

In 2013, Japan revised the Petroleum Complex Disaster Prevention Law to address the need for risk reduction of chemical accidents that could be triggered by earthquakes. This law also requires local and industry disaster prevention agencies to establish emergency management plans considering the potential consequences. The High-Pressure Gas Safety Law (revised in 2020) requires industrial facilities to arrange appropriate mitigation measures for the likelihood of chemical accidents that could be triggered by earthquakes and tsunamis. Japan also improved the national seismic code to reduce the damage to high-pressure gas storage facilities that could be affected by long-period earthquakes. Moreover, the Land Resilience Basic Law introduced in 2013 mainly to promote national resilience requires the need for comprehensive countermeasures against earthquakes and tsunamis triggering several chemical accidents to ensure business continuity in the petroleum complex located along the coastline.

3.4. Consideration of Natech risks at the international community level for disaster risk reduction

Besides the most significant efforts from the aforementioned countries, other international communities, such as the Organisation for Economic Co-operation and Development(OECD) and the United Nations Office for Disaster Risk Reduction(UNDRR), have also made efforts to reduce Natech risks. For example, OECD conducted two surveys on Natech risk management to member states, including South Korea, in 2009 and 2017 in order to investigate government efforts for reducing Natech risks, regulation requirements, good practices, Natech risk awareness, and Natech risk management system. The results from the 2009 and 2017 surveys imply that risk awareness and management of the conjoint natural and technological disasters are increasing gradually, and member countries have recognized natural hazards as a critical external risk factor for industries(OECD, 2009, 2020). However, there is still insufficient Natech-specific risk management, particularly risk assessment, due to a lack of comprehensive knowledge regarding the dynamics of Natech events(OECD 2020).

The UNDRR took the consideration of Natech risks into the Sendai Framework for Disaster Risk Reduction 2015−2030 (UNDRR 2015). The Sendai Framework emphasizes to manage complex risks, including natural and technological hazards and disasters, with the proactive engagement of multi-stakeholders. In recent, the UNDRR developed 10 principles to manage Natech risks based n the lessons from the past Natech experiences in 2020(UNDRR, 2020). Some examples of the principles included an integrated risk and consequence assessment, enhancing risk communication, multi-disciplinary stakeholder partnerships, effective co-ordinated emergency management planning, and the development of safety codes and regulations.

4. Lessons for the current practices in South Korea

There have been a few movements to identify gaps to manage Natech risks and understand Natech risk awareness by a number of researchers in South Korea. However, since South Korea has not faced remarkable Natech accidents yet so far, the conjoint natural and technological hazards and risks are often overlooked. Moreover, there is still insufficient attention to managing the risks of natural hazard triggering technological disasters in the current disaster risk and emergency management(Park and Cruz, 2022). The Act on Registration, Evaluation, etc. of Chemicals requires all stakeholders, including government, experts, and safety managers, to assess risk information regarding hazardous materials.

In order to implement effective risk management of the conjoint natural and technological disaster risk management, regulation requirements can be improved by the following lessons from the practices of other countries, considering national circumstances and the current domestic regulations. (1) Incorporate multi hazard risk assessment in the current relevant regulations: Natech risk management needs a comprehensive approach to vulnerability, coping capacity, emergency management resources, environmental impacts, and evaluation of Natech event scenarios.

(2) Establish Natech-specific regulations and land-use planning: the current regulations should consider specific natural and technological hazards to implement effective Natech risk management. In addition, land use planning should be developed to protect residents living near industrial facilities, environments, and eco systems.

(3) Strengthen coping capacity: Natech risk management should be supported by proactive engagement of legal institutions, private businesses, industrial operators, experts, and citizens within coordinated partnerships. However, there is a lack of manpower who are responsible for managing Natech risks and are well trained in all hazards risk management.

(4) Increase Natech risk awareness: The countries, the United States, European Union, and Japan, have promoted several programs to increase Natech risk awareness. In South Korea, depending on the affiliated organizations and duties, relevant stakeholders have different perspectives on Natech risks and Natech risk awareness that can determine successful Natech risk reduction. The stakeholders need to pay attention to Natech risks to build a safer society and reduce the risks.

5. Conclusions

The countries studied have regulations for technological accident prevention and measures to protect industrial facilities and citizens against natural hazards. However, only a few countries have advanced to prepare for Natech disasters. The countries require risk assessment and management considering specified natural hazards and lessons from past Natech disasters to reduce the Natech risks in the future. With increasing chances of occurring natural hazards, South Korea, that is one of the most industrialized countries and handling a large amount of hazardous materials, is no exception in preparing for the potential Natech disasters. The lessons and current practices from other countries would be valuable for successful conjoint natural and technological disasters and promoting a more resilient society against complex disaster risks.

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