Safety practice

Natech risk management in Japan after Fukushima – What have we learned?

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Summary

The Great East Japan earthquake and tsunami in 2011 triggered multiple releases, fires and explosions at chemical process installations. Based on the analysis of available accident data, this article identifies the main impacts and consequences and highlights gaps in Natech prevention, preparedness and response. It also presents changes in Natech risk management implemented in Japan after the earthquake and tsunami.

Keywords: Natech, risk management, lessons learned, earthquake, tsunami, Fukushima

Introduction

Natural hazards, such as earthquakes, floods, extreme low temperatures or lightning, can cause damage at hazardous installations, resulting in loss of containment and so-called natural hazard triggered technological (Natech) accidents[1]. Such accidents are a recurring threat frequently encountered in the wake of natural disasters[2,3,4]. In addition to direct impacts on public health, the environment, economy and the supply chain, Natech accidents can also hamper emergency response to the natural disaster, creating an additional burden for crisis management[5]. Natech risk is bound to increase in the future due to climate change, which can affect natural hazard trigger frequencies and severities, and human development, which increasingly puts natural and technological hazards on a collision course.

The Great East Japan Earthquake and Tsunami (GEJET)

On 11 March 2011, an undersea earthquake of magnitude 9 shook Japan and triggered a mega tsunami off the coast of Honshu Island. When it ran ashore, the tsunami inundated over 400 km^2 of land, leaving a trail of devastation behind[6]. While the earthquake produced very strong ground motion, shaking damage to non-industrial buildings was limited, bearing testimony to the effectiveness of Japan's advanced earthquake preparedness approach[7]. On the other hand, many hazardous installations located in the disaster zone were damaged or destroyed by the earthquake and/or tsunami. This suggests that even countries with high levels of general earthquake preparedness may be at risk of Natech accidents and that specific protection measures in industry are required.

Natech accidents galore

Surveys by government agencies identified numerous Natech accidents triggered by the GEJET, sometimes at the same installation at the same time. The Japanese Fire and Disaster Management Agency documented damage at 1404 oil storage and petrochemical installations due to the earthquake and at 1807 facilities due to the tsunami[8]. The Japanese Nuclear and Industrial Safety Agency collected data on earthquake- and tsunami-related damage at 50 high-pressure gas facilities and 139 other hazardous installations[9]. Another study analyzed 46 damage events based on data from open sources including public company data and interviews with competent authorities who were engaged in regulatory, monitoring, and/or first response activities[7]. These analyses concluded that while earthquake damage was frequent, it mostly led to only minor impacts or spills, such as via tank roof damage due to liquid sloshing caused by earthquake excitation, stretching of and leaking from flanges and tank-pipe connections, and damage to support structures. Tsunami damage, on the other hand, was much more severe, causing tank flotation and overturning, breaking of pipe connections, and ripping off of valves, e.g. due to debris impact [10](Figure 1). The inundation exacerbated the triggered loss of containment (LoC) events by dispersing flammable spills over wide areas and increasing the ignition likelihood. Several large-scale fires were the result[11].

Given the level of damage caused by the tsunami, many hazardous material releases must have occurred during the GEJET. However, aside from obvious LoC events that resulted in fires and explosions, it was difficult to obtain concrete information on releases of toxic or environmentally persistent substances in the aftermath of the natural disasters[12].

Storage tank farm fire, explosions and domino effect due to earthquake

An example of a major Natech accident caused by the earthquake were the fires and explosions at the LPG tank farm of a refinery in Chiba. Damage to the support braces of a tank during the main earthquake shock and buckling of the legs when the aftershock hit, led to tank collapse and LPG release from the severed connected pipes (Figure 2). The LPG spread and ignited, causing several consecutive BLEVEs and eventually destroying all 17 tanks

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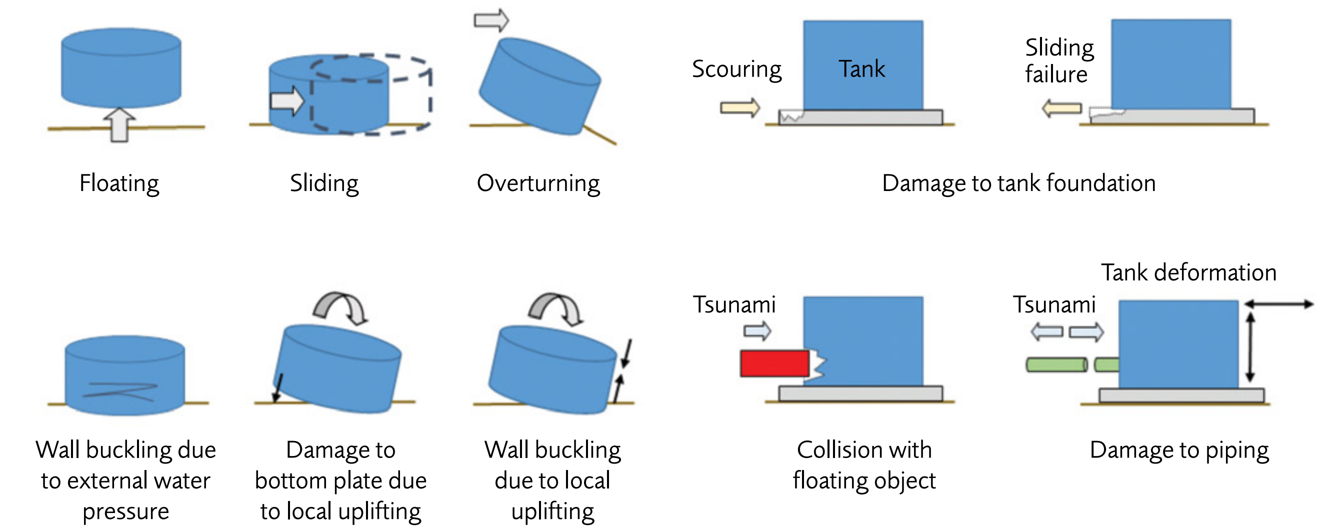

Figure 1 – Tank damage modes observed during the tsunami in 2011 (Adapted from Ibata et al. (2013)[11])

in the tank farm[7]. At least five explosions were documented, the largest of which created a fireball with 600 m diameter[13]. Burning missile projection and dispersion of LPG vapours triggered releases from asphalt tanks adjacent to the tank farm, as well as fires in two petrochemical complexes next to the refinery. Due to the multiple release sources, it was decided to let the fires burn until the fuel was exhausted. In the end, the fires at the LPG tank farm burned for ten days.

Overall, 1142 residents had to be evacuated due to the accident. Pieces of the destroyed tanks were later found in residential areas over six km from the tank farm[7]. The accident caused six injuries at the refinery, and three injuries at an adjacent facility where a fire was triggered. The refinery only returned to full operations two years after the accident.

Refinery fires due to tsunami

Another Natech accident whose pictures went around the world was the multiple tsunami-triggered fires at a refinery in the Sendai port area. The inundation depth at the site ranged from 2.5 to 3.5 m, killing four people and causing multiple loss of containment events at the same time[7]. In the refinery's loading facility, the tsunami hit a tanker truck, breaking a pipe in the process and releasing gasoline which ignited. It has been speculated that sparking from collision of a truck with refinery units could have been the ignition source[13]. The fire destroyed the entire loading station and also engulfed adjacent sulphur, asphalt and gasoline tanks (Figure 3). A large part of the western section of the refinery was destroyed in the blaze. The fires were eventually extinguished five days after the tsunami. In other refinery locations, LoCs occurred when pipelines broke after direct tsunami impact (Figure 4), or when the tsunami waters caused a tank to float which broke an attached pipe[7]. In both cases, heavy fuel oil was released but did not ignite. In the second case the LoC was aggravated by an open valve on the tank which underwent filling when the tsunami hit. The earthquake caused minor spills on atmospheric tank roofs due to roof vibration.

With an LNG tank from a different operator located immediately to the south of the burning refinery section and tsunami-triggered flammable releases in another industrial site south to the LNG tank, there was also a high risk of a domino effect. Emergency responders had to take great care to keep the releases from igniting to avoid heat impingement on the LNG tank from two sides which it might not have withstood without damage.

H. Nishi

Figure 2 – Buckling of tank legs due to earthquake

C. Scawthorn

Figure 3 – Burned and melted tanks at a refinery in Sendai port due to tsunami

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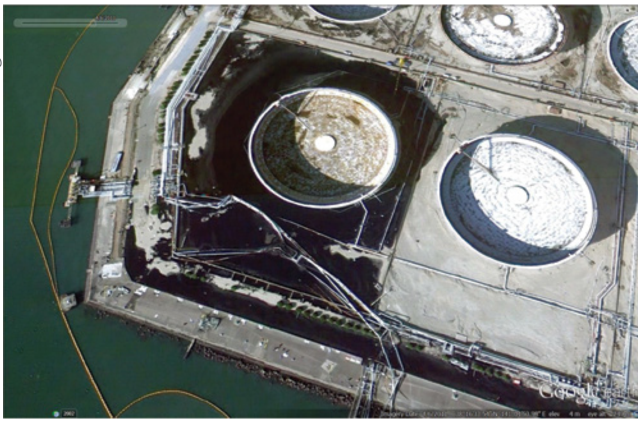

Figure 4 – Damaged pipelines and oil spill due to tsunami impact

Identifying the gaps

Analysis of the Natech accidents that occurred revealed a number of gaps in Natech risk management[7]. For example, the widespread damage and numerous LoC events suggest that vulnerabilities existed due to industrial development in natural hazard zones. With Japan being densely populated and subject to many different types of natural hazard, land use planning could not always keep industrial plants away from areas that are prone to natural hazards. Where additional protection measures were implemented to compensate for increased risks due to location (e.g. sea walls), they were often found to be insufficient, raising concerns as to the assumptions they were based on.

The analyses also suggest that preparedness in industry and by authorities was generally low, indicating a need for improving preparedness planning to include Natech scenarios and their specific features which often render them more severe. This includes the acknowledgment that cascading effects are more frequent during natural disasters. For example, both the operator of the refinery in Chiba and the competent authority admitted they were not prepared for coping with an accident of such severity. Also, there is a need to factor in conditions in which equipment may be exposed to higher stresses than those experienced during normal operation, such as during maintenance.

The fires and explosions at the Chiba refinery also highlighted the need for more active government oversight to monitor compliance with safety regulations and to carry out inspections. A combination of bad practice and violation of regulations was the root cause of the accident. The collapsed tank was under maintenance and had been filled with water already for 12 days when the earthquake struck. This almost doubled the weight considered in its design basis, rendering it vulnerable to earthquake impact. In addition, the manual override of a safety valve on an LPG pipe continuously provided fuel to the fires and allowed them to burn out of control[7].

Attention to chemical releases, unless posing a clear and immediate threat to the population or first responders, was low during the GEJET as other issues had to take priority (managing the Fukushima nuclear power plant accident and relief efforts in the disaster-stricken areas). This resulted in a scarcity of information on potential toxic hotspots or contamination levels of disaster waste, possibly creating health hazards during initial rescue operations, cleanup and reconstruction[12]. The situation was complicated by a fragmentation of responsibilities for environmental monitoring and cleanup between different ministries and local government officials. This highlights a lack of clear procedures on how to quickly identify chemical contamination after natural disasters and the need to include them in crisis response plans.

Accident analyses also identified a need to reassess the role of utilities and lifelines for preventing accidents and/or mitigating consequences which is often underestimated. Lack of power, water (cooling, firefighting), transportation (site access) or communication (coordinating response) can trigger or exacerbate an accident, as well as increase the risk of cascading effects[5]. At the refinery in Sendai, emergency response to the fires was delayed as debris from the tsunami had obstructed the access roads to the site. Firefighting could only start four days after the GEJET. Also, due to ignition of sulphur and subsequent toxic cloud formation, an evacuation order in a 2 km zone around the refinery was issued, further delaying response efforts[7]. If the specific characteristics of Natech accidents are not taken into account in preparedness planning, managing the accident successfully will be a challenge.

Other studies carried out after the GEJET highlighted the little information and disaster preparedness of local governments and residents for these types of events[14,15]. It was found that 65% of the facilities surveyed in a study had no programs or activities to communicate with the public regarding preparedness for hazardous materials accidents[15]. Problems regarding the roles and responsibilities of local and prefectural government during the events, as well as confusion among affected residents regarding the many evacuation orders given in the days that followed the main earthquake shock were also identified[14].

A new approach for Natech risk management in Japan

In Japan, chemical accident risk management is regulated by many different laws and regulations. At the time of the GEJET, only Japan's High Pressure Gas Safety Law explicitly addressed Natech risks due to earthquake and tsunami, requiring measures to be taken to reduce the associated accident risk[16].

E. Krausmann

Figure 5 – Strengthening of tank supports in the Sendai coastal area

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Following the GEJET, regulations and codes were amended, risk management guidance was prepared and research projects were launched to improve the protection of industrial facilities and equipment during earthquakes and tsunamis.

For instance, Japan has modified the seismic code for high-pressure gas storage tanks to minimise the damage to gas storage facilities that can be impacted by long-period seismic events causing liquid sloshing. The amended code also increases the seismic resistance of the supporting frames of pipe braces by reinforcing the intersection of the braces[17] (Figure 5). With a trend towards larger storage tanks, which translates into higher risks, adequate seismic design of the tank structure and foundation has become even more important[18].

Similarly, guidelines for managing earthquake risk at industrial parks were developed[19].This guidance, which focuses on area-wide assessment at industrial agglomerates, addresses performance levels and structural design issues but also highlights prevention and mitigation measures with respect to earthquake impact.

Furthermore, the so-called Land Resilience Basic Law was enacted in 2013. This new law requires the adoption of comprehensive countermeasures to ensure that major industrial parks remain in operation following large earthquakes and tsunami. Generally, industrial parks covered by this law are under the jurisdiction of the prefectural government. In 2017, a Cabinet bill modifying the High Pressure Gas Safety law, transferred part of the oversight to local governments. This is important, as industrial parks are located in highly populated coastal cities, such as Osaka, and Kobe, that previously had little or no say in the siting, permitting and inspection of facilities at industrial parks located in their cities. It can also facilitate preparedness of local residents for chemical and Natech accidents.

It is also important to note that the Great East Japan earthquake and tsunami highlighted the need to prepare for large-scale events that surpass design levels. Since then, the country has been adopting a two-hazard level system when it comes to earthquake and tsunami protection countermeasures. The two-level system acknowledges the fact that protection strategies should consider events below or equal to, and events above the country's design level requirements for infrastructure systems and hard countermeasures[20]. Hazard level 1 (L1) includes earthquakes of magnitude below or equal to Mw 8 and return periods of several 10-100 years, while hazard level 2 (L2) includes events of Mw 9 and return periods of 1000 years or higher. In the latter case, protection measures should include both hard and soft countermeasures, and the consensus that some level of damage is inevitable.

Japan has been relatively quick in learning from past accidents, amending regulations or implementing new ones when needed to reduce the risk from future disasters. The High Pressure Gas Safety Institute prepared risk assessment guidelines, and training workshops have been carried out around the country targeting industrial facility engineers, and health and safety staff, among others. One area that is lagging behind concerns risk information disclosure and efforts to improve disaster preparedness of residents living near industrial facilities. Recent typhoon- and flood-related Natechs in 2018[21,22], and 2019[23] have again called attention to the need for better preparedness of local residents when faced with these types of accidents, as well as the need for risk communication regarding these types of risk.

Conclusions

Numerous Natech accidents were triggered by the Great East Japan earthquake and tsunami, some of which with major consequences. This may appear surprising considering the advanced earthquake preparedness in Japan and its emergency-management capacities. Analysis of the available accident data confirmed the findings from other studies related to the dominant damage and LoC modes due to earthquake and tsunami and identified a number of gaps in Natech risk management at the time of the natural disasters. Japan has quickly reacted to address the main risk management deficiencies in industry revealed by the GEJET. But also beyond Japan the GEJET has left a lasting impression, and awareness of Natech risks has grown ever since, triggering a learning effort globally.

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