Natech accidents at industrial facilities. The case of the Wenchuan earthquake

Elisabeth Krausmann, Ana Maria Cruz, Bastien Affeltranger

Natech Accidents at Industrial Facilities – the Case of the Wenchuan Earthquake

Elisabeth Krausmann[1] Ana Maria Cruz[1] Bastien Affeltranger[2]

[1]European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen, Via E. Fermi 2749, 21027 Ispra (VA), Italy (elisabeth.krausmann@jrc.it)
[2]INERIS, Accident Risks Divison, B.P. 2 ALATA, F-60550 Verneuil en Halatte, France

Abstract

Natural disasters can trigger chemical accidents (so-called Natech accidents) with severe consequences on man or the environment. This work highlights the main characteristics of earthquake-triggered Natechs by describing our insights from a field trip to chemical facilities in the area affected by the 12 May, 2008, Wenchuan earthquake in China. Our preliminary results indicate that damage was most severe in older facilities with masonry and un- or poorly reinforced concrete structures being the most vulnerable. Debris impact and the shaking loads caused damage to and loss of equipment and pipes where hazardous-materials releases occurred. Emergency response on-site was hampered by a loss of lifelines.

Keywords: Earthquake, damage, chemical spill, hazardous materials, Natech risk

1. Introduction

On 12 May, 2008, at 14:28 local time, Sichuan Province in China was hit by a major earthquake. The seismic event, which had its shallow epicenter in Wenchuan county, reached a moment magnitude of $M_W = 7.9$ and left almost 70,000 people dead while injuring over 374,000 [1]. Over 5 million buildings are reported to have collapsed and many more were damaged. Direct economic losses due to the earthquake are estimated to exceed 140 billion US$ [2].

In addition to the human tragedy the Wenchuan earthquake and other recent major natural disasters worldwide have highlighted how the interaction between natural disasters and technological systems can exacerbate losses. Of particular concern is the impact of natural disasters on the chemical process industry owing to its major accident potential due to hazardous materials used or stored on site. In this case earthquake-triggered damage can lead to the release of (eco-)toxic, flammable and/or explosive substances with potentially severe off-site consequences. Commonly this type of chemical accident is referred to as Natech accident, a term which was first used by Showalter and Myers in 1994 [3] and which is derived from "*nat*ural hazard-triggered *tech*nological accident". It includes hazardous-materials releases from fixed chemical installations, but also spills from oil and gas pipelines [4]. There are numerous examples for earthquake-triggered Natechs such as the fire in a major refinery during the 1999 Kocaeli earthquake in Turkey [5], the fires in an oil storage depot after the 1994 Niigata earthquake [6], or the rupture of an oil pipeline during the Northridge earthquake in 1994 [7], to name a few.

There is very little information on the extent of the damage to and hazardous-materials releases from industrial facilities during the Wenchuan earthquake. Some of the hardest-hit areas are home to numerous chemical companies and a few Natech accidents have been reported [8, 9]. In order to assess the performance of the chemical industry the European Commission's Joint Research Centre in collaboration with the French National Institute for Risk and the Industrial Environment conducted a field trip in the areas affected by the earthquake in November 2008. This article describes some preliminary results of these site visits and briefly illustrates the main characteristics of earthquake-triggered Natech events using the Wenchuan earthquake as an example.

2. Damage analysis of chemical facilities

Prior to the Wenchuan earthquake Chinese design codes required buildings to withstand an earthquake intensity of VII on the Chinese Seismic Intensity Scale with repairable damage only [10]. In comparison, the earthquake reached intensity levels of XI in the regions near the epicenter [2]. The level of damage and destruction is therefore not surprising. The chemical industry follows the provisions of the codes but is also required to implement additional specific regulations in case a major accident potential exists [11].

2.1. Damage to buildings and equipment

In total we visited 18 industrial facilities during our field trip, with only one of them not having suffered any visible damage. In most of the visited facilities people were unharmed or only slightly injured and the impact of the earthquake was restricted to structural and non-structural damage to buildings, as well as to processing and storing facilities. However, in two sites over 275 workers lost their lives and many more were injured when warehouses, office and manufacturing buildings collapsed and buried them. Given the magnitude of the earthquake and the density of chemical facilities in the affected region this number is likely to be a low estimate.

During our site visits we noticed widespread building damage and collapse, in particular in installations located in areas subject to high peak ground acceleration values. Our findings suggest that the damage severity is directly correlated to the age of the installation, and older facilities not built according to the latest design codes suffered more severe and extensive damage. Moreover, the construction type significantly influenced a building's resistance to the earthquake loads with masonry and un- or poorly reinforced concrete structures being the most vulnerable (Figs. 1 and 2).

Fig. 1: Destroyed building at a chemical facility.

Falling debris from collapsing buildings and other structures resulted in major equipment damage. Debris impact also severed and crushed pipes both inside buildings and outside. In many cases we observed bending or severing of external pipes when connected tanks or buildings were displaced or collapsed (Fig. 3 and 4).

Fig. 2: Building collapse due to insufficient reinforcement.

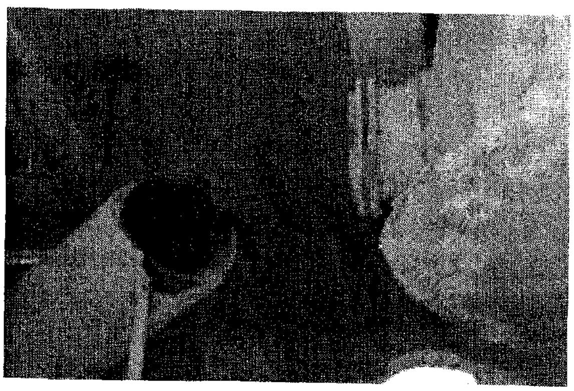

Fig. 3: Severed pipe.

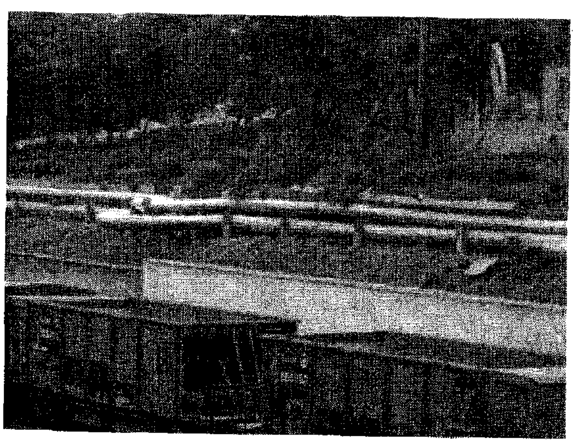

Fig. 4: Pipe crushing due to a fallen concrete fence.

Tanks and vessels were subject to a number of damaging phenomena during the earthquake. In some cases they were damaged by impacting debris or they failed under the unexpected shaking loads. Damage to or complete failure of tank and vessel foundations also resulted in toppling or tilting (Fig. 5). It is common during major earthquakes that storage tanks that are only partially filled experience liquid sloshing, which exerts additional forces on the tank shell and may eventually cause it to fail, releasing the tank's contents [5]. We have no information if this phenomenon played a role in damaging the tanks at the sites we visited. Pipe connections to tanks or pumps were sometimes severed.

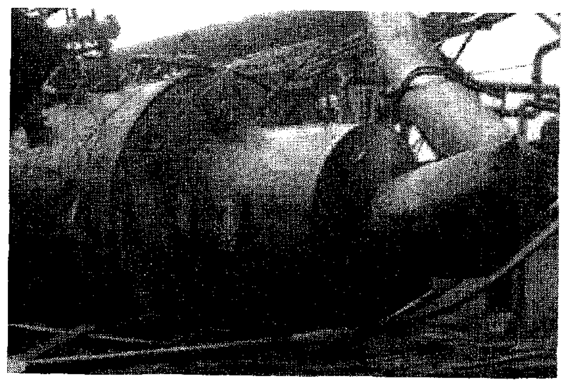

Fig. 5: Toppled vessel.

Several facilities visited experienced damage due to soil liquefaction which caused foundation failure and the sinking or toppling of buildings and other structures (Fig. 6).

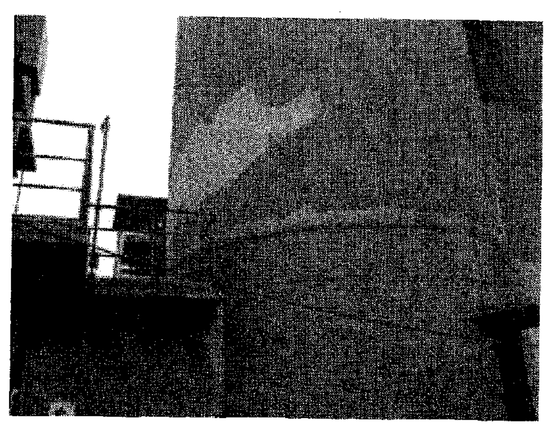

Fig. 6: Structural damage to a silo due to soil liquefaction.

2.2. Economic losses

Direct losses due to building and equipment damage, as well as indirect costs from plant shutdown and business interruption usually weigh heavily on companies that have suffered one or more Natech accidents during a natural disaster. According to company managers at the facilities we visited the direct losses exceed 240 million US$. At the time of our visit 6 months after the earthquake repair and reconstruction was still underway. Some facilities were still shutdown or had resumed production only partially. One plant director told us that he was negotiating a cheap loan with the government as otherwise his company would have to cease activities altogether. Costs due to plant shutdown and business interruption add significantly to the losses the chemical industry in the earthquake-affected areas suffered. With rebuilding times of sometimes years at the more heavily impacted facilities and fear of future severe earthquakes some affected companies have decided to move their production away from the vicinity of the fault zone.

3. Hazardous-materials releases

Many of the damaged tanks and severed pipes observed during the field trip contained substances that were toxic, flammable or explosive. However, information on hazardous-materials releases triggered by the earthquake is scarce. Releases were confirmed by residents of two chemical facilities who reported a pungent smell shortly after the earthquake, or the appearance of burned crops and other vegetation [8]. The Chinese Ministry of Environmental Protection confirmed the release of a significant amount of ammonia and sulfuric acid which polluted a river [12]. Sulfur burning and explosion was also reported [8]. With the general level of destruction both on- and off-site it is likely that any releases would have continued for days until the tank or vessel contents were exhausted. Since Sichuan Province has a high density of chemical industry that was constructed before the coming into force of more stringent seismic design codes the overall hazardous-materials releases triggered by the earthquake might have been extensive.

The hazardous-materials release modes at the visited facilities were typical as research on previous earthquake-triggered Natech accidents suggests [e.g. 5, 13]. Leaks and spills occurred when buildings collapsed on tanks and vessels or when pipes or pipe connections were severed due to debris impact or direct loading by the earthquake. In addition to toxic releases, fires and explosions were also triggered during the Wenchuan earthquake. A recent study indicates that the ignition probability is rather high upon release of a flammable substance during an earthquake [14].

4. Emergency response

Natech accidents invariably are a challenge for emergency response that has to deal with a natural disaster and a chemical accident that occur simultaneously. In addition, lifeline systems such as water or power supply, crucial for disaster mitigation, are likely to be unavailable. An aggravating factor is that some natural disasters, such as earthquakes or floods, usually have an extended impact area and may therefore lead to hazardous-materials releases from multiple sources at one chemical facility or from several affected hazardous installations simultaneously. If the specific characteristics of Natechs have not been taken into consideration in the emergency planning prior to the accident, crisis-management resources may have to be diverted from responding to the natural disaster to fight the chemical accident. In the worst case it can also mean that search and rescue operations, e.g. for earthquake victims still buried under collapsed houses, may need to be discontinued when hazardous-materials releases are imminent. This sadly happened during the Kocaeli earthquake where a major fire in a refinery threatened a neighboring fertilizer production plant, possibly leading to toxic releases, fires and explosions. Consequently, an evacuation order was given for residents who had to leave trapped family members and relatives behind [5].

We have little information on the emergency-response performance during the Wenchuan earthquake at the visited chemical facilities. There was a widespread loss of lifelines in the province and a subsequent breakdown of the electricity, gas and water supply which led to an interruption in production even in undamaged companies [8, 15]. Moreover, in some cases the on-site power generators or water services were also destroyed. It is safe to assume that structural and organizational prevention and mitigation measures were not designed for an earthquake of such magnitude. In the absence of water for cooling or fire-fighting purposes or emergency power to run safety systems we surmise that the release of hazardous materials in the hardest-hit installations would have been difficult to contain.

The level of destruction of buildings, roads and railroads was striking during the Wenchuan earthquake. This was due to the earthquake forces themselves but was aggravated by numerous landslides and rock falls that accompanied the earthquake. This highlights another problem of Natech accidents during which the applicability of standard civil protection measures cannot automatically be assumed. During a conventional technological accident with hazardous-materials release community leaders may choose to implement protection measures such as shelter in place or evacuation of residents. These choices may not be available in the case of a natural disaster as houses may have collapsed or roads may be blocked by debris.

5. Conclusions

There is evidence from recent Natech accidents that the chemical industry is vulnerable to the impact of natural hazards and disasters. Earthquakes are of particular concern as their occurrence cannot be predicted which precludes the possibility for early warning and thus the implementation of emergency safety measures. In addition, the spatial extent of earthquakes usually leads to simultaneous multiple releases not only from one facility but possibly from several, compounding the problems arising from the impact of the earthquake on the population, the environment and the economy. Therefore, Natech risk needs to be identified and assessed, in particular in densely populated and industrialized areas, giving due consideration to its multi-hazard nature.

The findings from our field visit to industrial facilities affected by the Wenchuan earthquake confirm the observations made during other earthquakes in terms of typical Natech damage and failure modes, as well as hazardous-materials release potential and mechanisms. They also highlight the potential for a loss of lifeline systems to cause interruption of production, as well as the inability to prevent and/or mitigate a chemical accident. The Wenchuan case shows that a realistic assessment of the expected earthquake severity and the resulting forces on buildings and other structures is required to evaluate and if necessary improve the seismic resistance of industrial facilities to avoid building collapse, as well as debris formation. One already positive move in this direction is the updating of the seismic design code after the Wenchuan earthquake while some companies have opted for design event magnitudes higher than those requested by law.

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