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NaTech Risk Analysis in the Context of Land Use Planning. Case Study: Petroleum Products Storage Tank Farm Next to a Residential Area

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Natural disasters affect communities in a negative way throughout the world and their effects are expected to become more severe, as it is extremely difficult to keep up with resilience measures and disaster risk reduction actions in the rapid changing societal context. Major accidents within industrial sites can be caused by internal factors, such as equipment malfunction, human error, failure of safety measures etc., as well as by external factors, such as natural events – called NaTech events. The present paper focuses on the case study of a tank farm for the storage of petroleum products, located in a high seismic risk area in the South-Central part of Romania. The aim of the paper is to emphasize the difference between the individual and societal risk results in case of internal technological accidents and in case of adding a NaTech event triggered by a high magnitude earthquake in the area, for the same tank farm. Results highlight the fact that quantitative risk assessments which take into account NaTech scenarios should be included in the risk analysis process for industrial sites and for land-use planning purposes as well.

1. Introduction

Natural disasters affect communities in a negative way throughout the world. As the climate changes are becoming more obvious from season to season, urban areas become more crowded and expand fast in pursuit of economic development, the effects of natural disasters are expected to become more severe, as it is extremely difficult to keep up with resilience measures and disaster risk reduction actions in the rapid changing context.

Major accidents within industrial sites can be caused by internal factors, such as equipment malfunction, human error, failure of safety measures etc., as well as by external factors, such as natural events – called NaTech events (Krausmann et. al, 2011). These natural events, such as earthquakes, floods, tsunamis, lightning, landslides, wind (from tornadoes or hurricanes) etc. can cause severe damage to the process equipments, storage tanks, pipes etc., leading to the release of hazardous materials, environmental pollution, fires, explosions and toxic dispersions (Vallée and Duval, 2012). Accident database analyses carried out recently show that at least 3 % of the reported major industrial accidents were caused by natural events (Cozzani, 2010).

NaTech disasters, as the Tohoku earthquake and tsunami in Japan, 2011, which caused the explosion of the Fukushima nuclear plant, the partial destruction of the Chiba refinery and damages at other 44 chemical establishments (Krausmann and Cruz, 2013), or the Kocaeli earthquake in Turkey, 1999, causing massive fires at the TUPRAS Izmit refinery, the spill of 6500 t of acrylonitrile at the AKSA acrylic fiber production plant and many other NaTech events (Girgin, 2011), have shown their destruction capability

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leading to the conclusion that specific NaTech risk assessment methodologies should be used for disaster prevention and mitigation of the consequences.

Systematic NaTech risk assessment methodologies and mapping tools have been developed, such as the RAPID-N web-based tool, applicable for earthquakes (Girgin and Krausmann, 2012), the method developed by INERIS (French Institute for Industrial Environment and Risks) considering floods (Vallée and Duval, 2012) or the quantitative NaTech risk assessment methodology presented in the work of Antonioni and co-workers (2009a) considering both earthquakes and floods.

The present paper focuses on the case study of a tank farm for the storage of petroleum products, located in Ploiesti, which is a seismic area in the South-Central part of Romania. The tank farm pertains to a refinery built over 100 years ago. During the World War II it was partially destroyed and was rebuilt after 1948. The way of thinking was that workers needed to be as close as possible to the workplace, in order to streamline the production process and thus the economic development of the area, and as such a residential area was built next to the refinery, approximately 20 m away from the tank farm boundary.

The aim of the paper is to emphasize the difference between the individual risk (IR) and societal risk (RS) results in case of technological accidents having internal causes and in case of adding a NaTech event triggered by a high magnitude earthquake in the area, for the same tank farm. A number of 15 tanks of the 46 present in the tank farm were selected, being the closest to the inhabited area. The analysis takes into account escalation effects from the reference seismic event and simultaneous damage probabilities for the tanks considered in the case study.

2. Case study: comparative analysis of technological and NaTech risks

The earthquake hazard in Romania is induced mainly by the Vrancea seismic area, located beneath the Southern Carpathian Arc (Ardeleanu et al., 2005), which is considered to be one of the highest seismic risk areas in Europe (Sokolov et. al., 2007). For NaTech risk assessment, recurrence periods of 475 years are typically used for “important” sites, while for “very important” and “of special importance” sites, recurrence period of 1,000 and 5,000 years are used (Cruz et. al, 2004). For the studied site a recurrence period of 475 years can be taken into consideration, as this value, along with 100 years recurrence period is recommended by EUROCODE 8 (2003) for drafting seismic hazard maps for the design of structures for earthquake resistance (Ardeleanu et al., 2005). The selected site is located approx. 120 km South-West of the center of Vrancea seismic region and the highest Peak Ground Acceleration (PGA) can reach 3.5 m/s^2 (Sokolov et al., 2007) (Figure 1) with an intensity of approx. 8.7 MSK (Leydecker et al., 2008). As such, studying the NaTech scenario for the selected case study is highly justified.

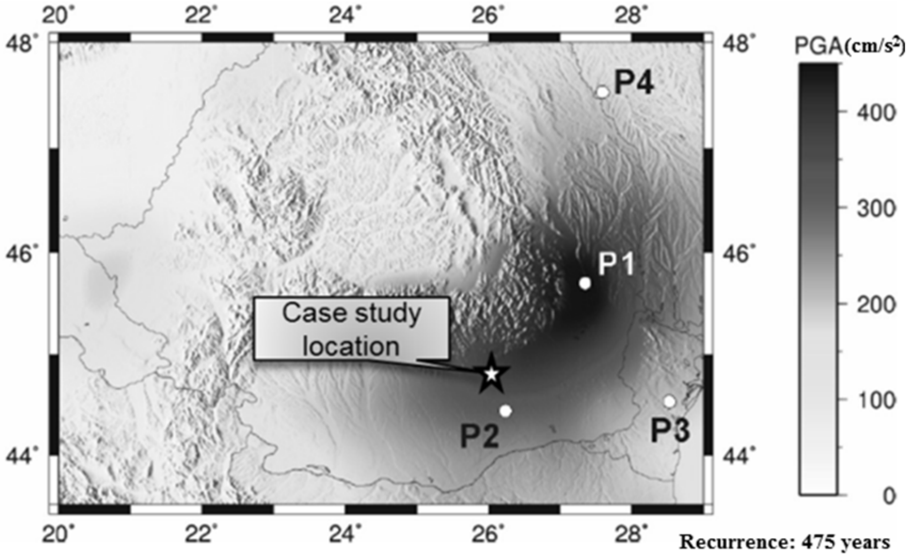

Figure 1. Probabilistic seismic hazard map of Romania (source Sokolov et al., 2007).

The substances present in the 15 tanks of the tank farm considered are: n-hexane, n-hexadecane, xylene and liquid fuel oil (n-undecane considered in the simulations). The tanks are vertical cylindrical stainless steel single wall tank, with storage capacities between 170 to 2,500 m^3. The tanks are anchored and the bund of the tanks is made of earth berms (dikes).

The residential area in the vicinity of the tank farm is comprised of single store houses. As no reliable data was available regarding the exact number of inhabitants for this area, an arbitrary value of 3 inhabitants per house was used, thus obtaining a population density of 39.13 inhabitants/ha for the studied area, constituted mostly of refinery workers and their families. The population presence was averaged from standard values for day and night given in Purple Book (Uijt De Haag and Ale, 2005), to 96 % indoors and 4 % outdoors, 100 % presence probability.

The possible accident scenarios were analysed in the preliminary hazard analysis and simulations were performed for the following scenarios: releases, pool evaporations, fires in bunds, flash fires, vapour cloud explosions (VCE) and internal tank explosions. The simulations of VCEs showed no results due to the low congestion of the lay-out considered. The flash fire simulations showed results only in case of unfavourable meteorological conditions (Pasquill stability class F; 1 m/s wind speed). The confined explosion simulations did not show significant effects for the residential area. The results of the simulations showed that only fires in bunds can present dangerous consequences for the population in the residential area, therefore only these were considered further in the IR and SR calculations. The calculations were made using ARIPAR 4.0. risk assessment tool (Spadoni et al., 2000).

3. Results and discussions

The loss of containment (LOC) frequency for the catastrophic rupture of one tank due to technological (internal) causes was selected from the literature: F = 5×10^{-6} y^{-1}, (Uijt De Haag and Ale, 2005). The LOC frequency due to the seismic event was estimated based on data for a reference seismic event with a recurrence period of 475 y (feq = 2.11×10^{-3} y^{-1}) and a conservative estimation of PGA of 3 m/s^2 (0.306 g) (Sokolov et al., 2007). The k_1 and k_2 coefficients values selected for the Probit function were k_1=4.66 and k_2=1.54 (Antonioni et al., 2009a). The calculated damage probability (Pd) of a tank in case of an earthquake resulted to be 1.52×10^{-2}.

However, different probabilities may be obtained considering the simultaneous damage of more than one tank. Therefore, the calculation of the frequency for each possible combination of simultaneous damage to the tanks due to earthquake is needed. A cut-off value for this frequency is applied (10^{-10} y^{-1}) (Antonioni et al., 2009b). This cut-off value is considered to be credible for the relevant combinations of 1 to n tanks (from the total 15 tanks) which could be damaged at the same time by the earthquake. For this reason, the calculation procedure for the estimation of domino events frequencies has been applied (Cozzani et al., 2005). The results of the calculation are presented in Table 1.

Table 1: Calculation of frequency of sets of combinations of tanks damaged simultaneously in case of the reference earthquake event

Number of tanks	Number of combinations	Probability of damage combination	Frequency of each combination (events/y)
0	1	0.794	1.67×10^{-3}
1	15	0.012	2.60×10^{-5}
2	105	1.92×10^{-4}	4.04×10^{-7}
3	455	2.98×10^{-6}	6.28×10^{-9}
4	1365	4.62×10^{-8}	9.76×10^{-11}

The total number of combinations resulted is 575, which is the sum of combinations within the credible cut-off frequency.

The acceptable individual risk limit values used for LUP purposes, accepted in several EU member states, are 10^{-5} y^{-1} upper and 10^{-6} y^{-1} lower limits (Duijm, 2009; Trbojevic, 2005).

The residential area is inside the lower limit for IR in all scenarios, except for the scenario involving the fire in the bund of tanks A13-A15, since these tanks are located further away from the residential area. In the case of the fire in bund of tanks A7-A10, also the upper limit (10^{-5} y^{-1}) contour of the IR includes the residential area.

From the comparison of Figure 2 with Figure 3 it can be observed, that when adding NaTech scenarios to the risk analysis, the IR level for the selected tank farm has increased with one order of magnitude, and a part of the residential area is situated within the unacceptable threshold contour of IR (10^{-5} y^{-1}) for LUP purposes.

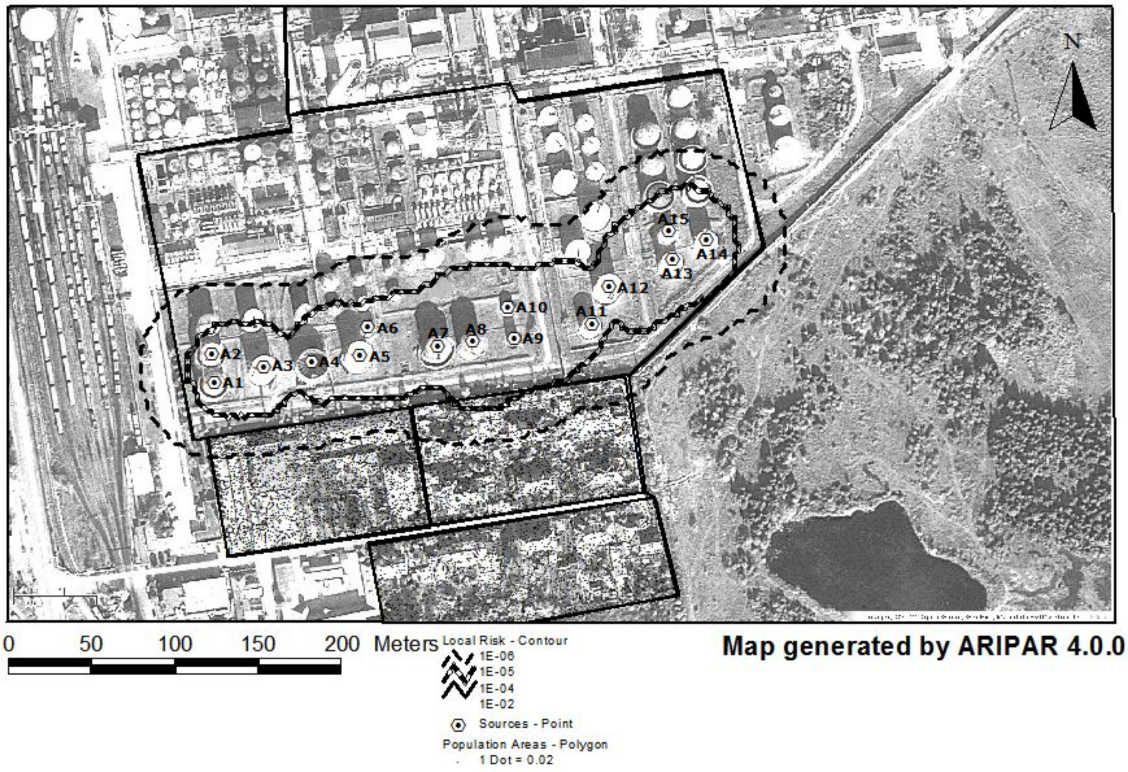

Figure 2: Individual risk for fire in bund scenarios for tanks A1-A15 – Internal technological causes

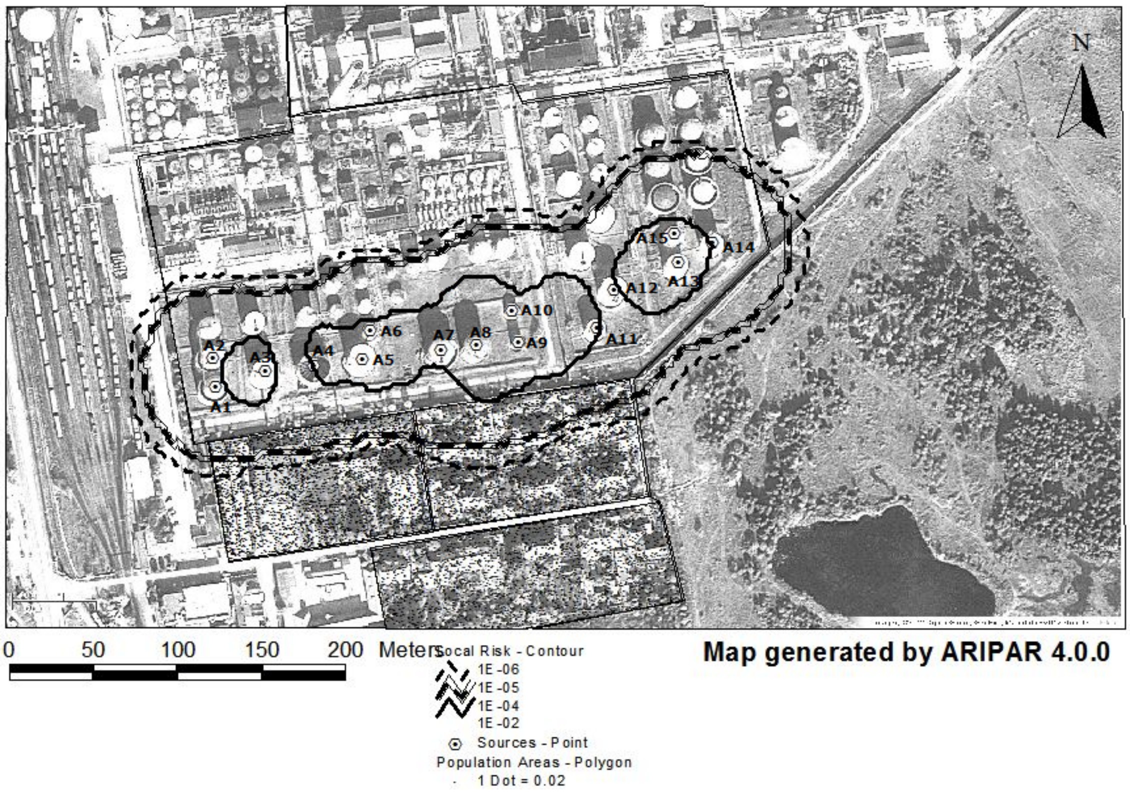

Figure 3: Individual risk for fire in bund scenarios for tanks A1-A15 - total risk: technological and NaTech causes

There is a significant increase in the societal risk as well when taking into consideration both technological and NaTech causes. A side by side comparison for SR considering technological causes versus total causes (technological and NaTech causes) for the site is presented in Figure 4. As expected there is an increase in the frequency for a given number of fatalities (due to the high frequency of the reference seismic event) and also some additional scenarios with an increased number of fatalities due to the simultaneous failure of different tanks are present.

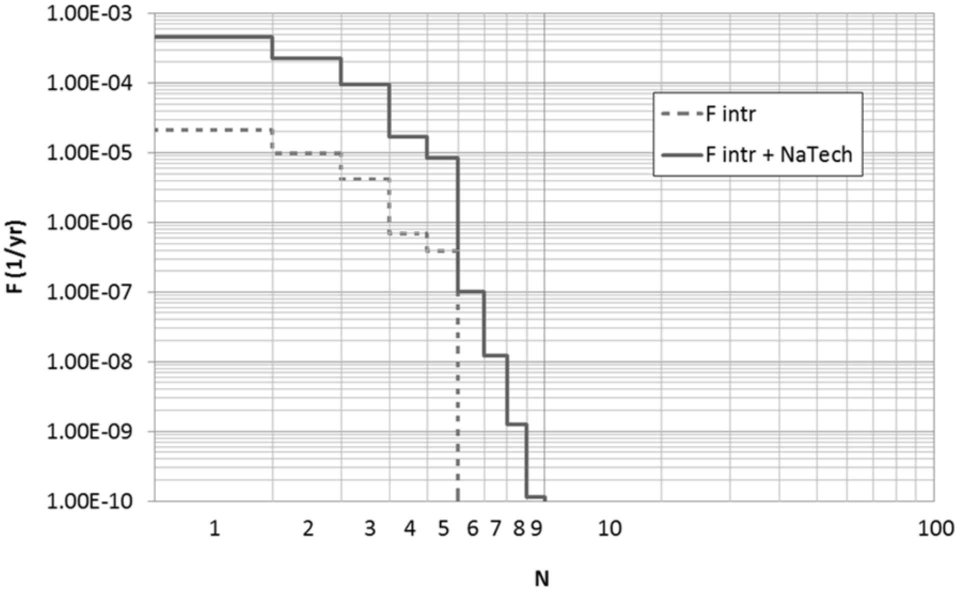

Figure 4: Comparison of societal risk F-N curves for fire in bund scenarios for tanks A1-A15, where F intr: cumulative frequency considering internal technological causes; F intr + NaTech: cumulative frequency considering internal technological causes and NaTech event.

4. Conclusions

The case study presented in the paper focuses on the importance of NaTech risk assessment for LUP aspects, especially in case of industrial sites located in natural hazard prone areas and also located in the vicinity of residential areas.

From the results of the preliminary risk assessment and of physical effects analysis (not included in this paper) it was concluded that only “pool fires in bunds” scenarios should be considered further in the quantitative risk assessment. IR and SR calculations have been performed, both for intrinsic technological accidents and for scenarios considering also NaTech event triggered by a high magnitude earthquake in the area, for the same hydrocarbon storage tank farm. The results obtained emphasize the importance of the inclusion of NaTech scenarios in the risk assessment, having a significant contribution in the overall risk level. In this case, considering the NaTech scenarios the IR and SR have increased with one order of magnitude, exceeding the acceptable risk levels used in LUP, for a big part of the residential area.

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