The Analysis Of Na-Tech Risks By Time-Based Index

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The interaction between catastrophic natural events and industrial installation (Na-Tech) can add further issues on natural, post-accident management. As it concerns land use planning and emergency actions, for instance, a major issue of Na-Tech risks regards the prediction of the possibility of effective and safe recovery of workers and people, keeping into account both joint industrial and natural hazards. In this work, a time-based analysis is defined and figured out for typical industrial facilities, and for different urban activities for both long-term alarm (as in the case of volcanic hazard or tsunami) and short-term alarm (as earthquake). The methodology allows quick assessment of targets on which to concentrate prevention and mitigation efforts in the framework of land use planning and industrial management and to drive emergency resources.

1. Introduction

Natural catastrophic events may be able to affect the integrity of industrial structures and possibly lead to loss of control of production processes. Consequently, if industrial facilities store large amount of hazardous materials, accidental scenarios as fire, explosion, or toxic dispersion can be triggered, thus possibly involving population living in the close surrounding or in the urban area where the industrial installation is located. Eventually, the analysis of natural-technological (Na-Tech) mutual interaction is necessary for the development of methodology for risk management practice, for risk assessment and for emergency planning. On the other hand, simplified tools are mandatory because the number of possible scenarios is often dramatically high when large installations or areas are considered. Despite these considerations, a recent analysis showed that none of the European countries has specific Na-Tech risk and emergency management programs in place (Cruz et al., 2004). In the following, some advancements for the analysis of natural-technological risks are presented, with specific reference to earthquake (short-term scenario) and volcanic hazards (long-term scenario). Results add some insight in dealing with crosscutting risks as Na-Tech. The analysis is part of a large project of the Department of Civil Protection for the analysis of industrial risks in the surrounding of Mt. Vesuvius in Napoli, aiming at emergency planning for population in the case of eruption.

2. The Definition Of Na-Tech Index

Based on the analysis of several past natural events, Lindell and Perry (1996) and Cruz (2005) singled out some general features of Na-Tech. To their point of view, when earthquake, floods or tsunami or any large-scale destructive natural event occurs, territorial and urban systems, which are likely to include industrial areas/facilities, are expected to face simultaneously heterogeneous impacts on exposed elements (human, goods, and environment). More specifically, technological accidents may be triggered by natural events and their effects may add or worsen the condition of people and environment struggling with the natural event effects. The combination of natural and technological hazards may also induce an overload of emergency services, which are usually shaped to face single events. To this regard, it is worth noting that safety and rescue operations could be impeded by the shortage of resources (water, energy) or by the reduction of accessibility due to debris, traffic of escaping people. Eventually, as recognized by Lindell and Perry (1996), the greatest concern of Na-Tech is regarded to the potential for overloading emergency response system and compromising its ability to minimize losses to persons and property. However, we think that further concerns should be linked to the shelter location, to land use planning, to the choice of appropriate mitigation systems, to the definition of predictive simplified tools, which are also useful for decision-makers in the case of catastrophic natural events.

To these aims, our analysis has been addressed to the definition of sequences of both natural and industrial accident in order to compare systematically the characteristic times of occurrence of industrial accidental scenarios and time needed for emergency action or the time needed by people to reach safe recoveries. A time-based index (NaT) is then defined in order to allow a quick assessment of industrial activities on which to concentrate prevention and mitigation efforts, to drive emergency resources, and to develop early warning measures:

$$\mathrm{NaT} = \beta \cdot \frac{\tau_{\mathrm{action}}}{\tau_{\mathrm{spreading}}} \tag{1}$$

In Eq. 1), $\tau_{spreading}$ refers to the characteristic time for the natural event to occur and to reach the industrial and civil targets starting from general alarm. This time depends on early warning and it is very long for eruption, as the evacuation plan begins days before the actual eruption, whereas it is negligible for earthquake. The time for action τ_{action} includes the characteristic time for emergency action or for the evacuation of population after alarm. Quite clearly, the greater the value of NaT, the higher is the possibility for the natural event to produce damages to the population or to raise difficulties for emergency actions. Values of NaT largely greater than unity mean real un-safe condition whereas NaT values near zero means that NaT are unlikely.

In Eq.1), the time for spreading includes also the time needed for the trigger of industrial accidental scenario after structural damage by the natural phenomenon, thus including the time to trigger the phenomenon and the time for the propagation vector (heat radiation for fires, overpressure for explosion, concentration for toxic dispersion) to reach any general target (urban context or specific building or safe shelter). This time is defined as τ_{ind} and is sketched in Table 1.

Fires (including pool fire, tank fire, buildings, and warehouses) are likely to occur after natural events. For Na-Tech scenarios, these phenomena may interact with surrounding urban context only after the fire is fully developed from ignition to the flash-over. The flash-over time depends mainly on the grow rate of fire α, expressed in $kW \cdot m^{-2}$, which divides the fires in four typology from slow fire to ultra-fast fires. Examples of calculation for warehouses and pool fires are given in Hietaniemi and Mikkola (1997).

Hydrocarbon pool fires are identified as fast fires ($\alpha \approx 0.04$ kW m^{-2}), and time to flash-over are typically of 3-5 minutes after ignition. To this regard, it is worth to consider that strong earthquakes are characterized by equipment failures, tube shifting, large atmospheric static energy, and ignition of flammable material (gas or vapour) is very likely, i.e. early ignition should be considered rather than late ignition scenarios. For warehouses, times of about 10 minutes are the minimum values for large fires.
The BLEVE/fireball phenomena can occur as further consequence of fires. The duration of these phenomena is of the order of seconds, and the time for spreading is only related to the time for equipment failure. This time is clearly dependent of specific condition and equipment. In previous work, Salzano et al. (2003) have demonstrated that the minimum time for either “total loss of containment” (without explosive escalation and eventually with fireball) is about 5 minutes, whereas longer time and very rare and specific conditions (15-30 minutes) are needed for explosive BLEVE/fireball to occur.
Explosion in confined equipment are very dependent on the loss of control of equipment, and cannot be defined in general sense. However, the effects of these types of phenomena are generally confined within the facility and can be neglected in the Na-Tech analysis. Different option should be proposed for Vapour Cloud Explosion. In this case, the effect can be destructive over large areas but as cited above, late ignitions are unlikely. Finally, water and earth pollution due to the release of liquid substances on the ground or in river/sea adjacent to the industrial facilities are also ruled out, as the effects on structures are negligible, whereas the effects on people are only to be considered on the long-term, considering the time for restoring the earth/water conditions. These issues are out of the scope of the present work. Finally, dispersion of toxic substances is the real issue, as characteristic time can last from few seconds (but small areas are of concern) to minutes or even hours.

Table 1. Characteristic time for typical industrial accidental scenarios triggered by natural events.

Phenomenon	State	Description	τ_{ind}
Fire	Solid	Large fire of buildings, structures, warehouses	> 10 minutes (flash-over)
Pool, Tank Fire	Liquid	Large fire of liquid flash point	Minutes (flow rate, ignition delay)
Flash fire		Flammable cloud	Seconds/minutes
BLEVE/Fireball	Gas, Vapour	Hot combustion products expanding in the atmosphere	> 5 minutes
Jet fire		Hot combustion products in the atmosphere	Seconds
Point-source	Solid	Explosives	Seconds
BLEVE	Pressurised gas	Equipment failure, fragments	> 5 minutes
Confined explosion	Liquid, Gas, Vapour	Equipment failure, fragments	Seconds to hours
Vapour Cloud Explosion	Gas, Vapour	Large scale explosion	Seconds
Pollution	Liquid	Release on water/earth	Hours/Days
Toxic dispersion	Gas, Vapour	Gas/Vapour release	Seconds/ Hours

When a natural event occurs, people run spontaneously and chaotically from the buildings, unless structural damages to buildings or to infrastructures hinder the

evacuation. The time of action τ_{action} is then the time for the evacuation of people towards safe shelter, either with respect to industrial accidental scenarios or with respect to natural events (τ_{escape}). To this regard, we intend shelters as "wait areas" in existing Civil Protection emergency plans against natural and technological hazards. Where no plans exist, they could be identified among those open spaces sited outside the major industrial accident-prone area, freely accessible (e.g. public squares, parks). The escape time is obtained as the ratio between the length of the path L to reach a safe area (e.g. shelter) and the average human velocity of escape v_h. To this regard, some authors state that human velocity, when escaping, ranges from 0.2 to 0.5 m s^{-1} in case of smoke conditions (Wright et al. 2001) to a maximum of 5 m s^{-1} (De Pinna 1998). If taking into account that some panic could reduce people average velocity thus delaying their capacity to take decisions, an average of about 1 m s^{-1} velocity can be considered for v_h. In the case of tall buildings, time for evacuating higher floors should be considered. To this regard, Pauls (1987) states that approximately 10 s per storey for small buildings to approximately 20 s per storey for large buildings are needed.
In the case of emergency management, τ_{action} can be considered as the time for emergency teams to operate or the time for the emergency procedures (τ_{emerg}), either internal or external to the production plant. Quite clearly, the possibility of mitigating or preventing the accidental scenario reported in Table 1 depends on the ratio of this time with the spreading time, and another use of NaT number is possible. Quite clearly, in the case of very long term warning as the volcanic eruption, τ_{action} is typically shorter then $\tau_{spreading}$. On the other hand, in the case of short time scenario as earthquake, the intervention of teams or procedures is certainly post-event, unless - at least in the next future - Early Warning Systems (EWS) are adopted.

2.1. Definition of β

The enhancement term β is the unity in most cases, but it can assume values close to zero, which refer to the un-applicability of NaT because no Na-Tech event is possible for the low intensity of natural event, or larger values when natural event is so catastrophic that Na-Tech events are negligible and the two times are strongly affected by the intensity of the same natural phenomenon (e.g. all roads and buildings are completely destroyed by earthquakes and auxiliary systems are not operative).
For the earthquake action, β takes into account the threshold values with respect to the intensity of earthquake (expressed generally by a single degree of freedom for the sake of simplicity, e.g. Peak Ground Acceleration) which are able to damage structurally the equipment. In its general meaning, $\beta_{earthquake}$ is zero for any value below the threshold value for the intensity of earthquake (generally Peak Ground Acceleration, PGA), which identifies large releases of hazardous materials from containment system. Then, it can assume values that grow exponentially with the same intensity variable (see Salzano et al., 2003; 2007 for further details).
For the case of volcanic eruptions, threshold values refers only to the maximum distance reached by any phenomenon in the surrounding of volcano once defined a specific Volcanic Explosion Index (VEI), which refers to the predicted explosive intensity of eruption. To this regard, it is worth mentioning that our analysis is mainly referred to the zone where main natural destructive phenomena occur and emergency plans address the forced evacuation of people after alarm (the "red zone" in the case of

Vesuvius). However, other zones are of concern for volcanic Na-Tech as the so-called yellow zone, which is evacuated only after the main eruption.

3. Nat Analysis For People Safety

In the case of earthquake, the time for the trigger of structural damage is of the order of tens of seconds. Hence, only the time for the industrial accidental scenario is important when calculating the time of spreading. On the other hand, the warning time for the volcanic eruption, for the case of Vesuvius, is of the order of days (DPC, 2001).
Regarding the population, the time for reaching safe shelter or to go out buildings and reach open areas, unless catastrophic earthquakes, is of the order of minutes. The ratio of the two times is then reported in Table 2, keeping into account that large distance for the propagation vector of accident scenario are considered and that some accidents are not considered in the analysis (in particular early ignition rules out late ignition phenomena as Vapour Cloud Explosion and flash fire). Quite clearly, β is considered the unity for the sake of comparison.

Table 2. NaT value for the interaction between people and industrial accidental scenarios triggered by earthquake or volcanic eruption.

Phenomenon	NaT earthquake	NaT volcanic
Fires (Pool, Tank, Flash, Solid)	< 1	$<< 1$
Point-source explosion	> 1	$<< 1$
BLEVE/Fireball	> 1	$<< 1$
Toxic dispersion	Scenario-dependent	Scenario-dependent

In Table 2, volcanic Na-Tech risks are only related to the dispersion of toxic products, as the cloud can reach un-evacuated areas. All other accidental Na-Tech risks are negligible. Regarding earthquakes, Na-Tech are almost negligible for fires, as small areas are of concern (and people can be easily evacuated) and early ignition is likely (for flash fire). Hence, the main problem is the emergency coping, which draws resources to the people safety post-natural event. On the other hand, point-source explosion, BLEVE/fireball and toxic dispersion can give Na-Tech. The case of BLEVE/fireball can be however restricted to over-ground tank as large pressurized LPG sphere. It is also worth mentioning the mounded or underground tank cannot give the explosion of the tank and the subsequent fireball. On the other hand, point-source are generally confined in the industrial area and are not able to involve the people living in the surroundings of industrial installations. As a conclusion, dispersion of toxic gases and BLEVE/fireball of over-ground tanks are the only scenarios to keep into account.
For BLEVE/fireball, rapid evacuation in the radius of fireball is necessary. However, this procedure is difficult in the case of strong earthquake. Besides, the effect of BLEVE (the blast wave) and fireball are generally confined in relatively small areas (in dependence of mass of fuel involved). As a consequence, NaT is unavoidable and emergency coping is affected. Preventing measures for earthquake are however possible in terms of structural measures.
Regarding dispersion effects, at least in the far field, the only parameter which is essential is now the velocity of cloud nose, which can be considered for the evaluation

of time of spreading. To this regard, differences between lighter and heavier than air vapour/gas and release rate should be mentioned. To this regard, the experimental and modeling work by Khan and Abbasi (2000) can be used. Indeed, the velocity of cloud due to dispersion (u_{cloud}) is linearly dependent on the natural logarithm of the distance (d) of the cloud border from the release point, through two coefficient k_1 and k_2, which depend on the a-dimensional parameter Q_f, which depends on the the ratio of air density to gas density at any point along the section of cloud and on the ratio of wind velocity over release rate expressed in terms of vent speed:

$$u_{cloud} = k_1(Q_f) + k_2(Q_f)\ln(d) \tag{2}$$

$$Q_f = \frac{v_{wind}}{v_{release}} \cdot \frac{\rho_{air}}{\rho_{gas}} \tag{3}$$

The ratio of density in Q_f is however about the unity, at least in the far field. Typical range of wind velocity ranges from 0.5 m s^{-1} to 10 m s^{-1}. The velocity of release depends on the storage conditions and can range from few centimeters per second in the case of pool evaporation to sound speed in the case of pressurized gas release. Simple analysis shows that, in the far field, the velocity of cloud grows with distance whatever the value of Q_f and that only in the very far field it reaches the wind velocity, which can be finally conservatively assumed for NaT analysis.

4. Nat Analysis For Emergency Coping

The application of NaT number can be applied to emergency coping for the definition of priorities aiming at preventing Na-Tech risks rather than mitigating (NaT_{emerg}). It's important noting that the value of NaT_{emerg} can attenuate the NaT value for people, i.e. it is correlated to the definition of β in Eq.1) as for very small values, no accidental scenario are likely.

In the case of short term alarmed natural events, as earthquake, pre-accident structural reinforcement is the classical prevention method. However, in the next future, Early Warning Systems (EWS) may be adopted successfully for the rapid shutdown of process operations. Indeed, due to the short time for response, only automatic systems can be effective, whereas manual safety operations are quite slow and NaT can be very large because the τ_{action} grows consistently. Another important application of EWS regards the transportation system, either on sea or on earth by rail or road. Quite clearly, if automatic EWS are not installed, NaT_{emerg} is always greater than one.

Figures 1 and 2 reports the NaT_{emerg} number for atmospheric storage tank (anchored and unanchored, full level) and for pressurized storage tanks (horizontal, fill level = 80%), taking into account the arrival times of seismic wave (50 s and 100 s), and considering an automatic, short operating safety system (τ_{action} = 30 s).

Results show that, for the assumed conditions, PGA = 0.6 g is the most general safe threshold value for Na-Tech occurrence, either for atmospheric or pressurized equipment. The similarity of NaT of pressurized equipment with that of atmospheric tank is due to the different level of risk state. To be more specific, pressurized equipment may undergo to small shell structural damage and large release of flammable gases at the same time (hence higher risks), whereas atmospheric tank can produce large

accidental scenario only for large content release, which in turns may occur only for large structural damages.
For the volcanic risks, the time for emergency action is large, and the analysis is shifted to the priorities and specific procedures. Indeed, the value of NaT_{emerg} is ever smaller than unity. However, in the yellow zone, emergency actions starts are defined post-eruption and few hours are available for operations. Further analysis will be devoted to these aspects in the next future.

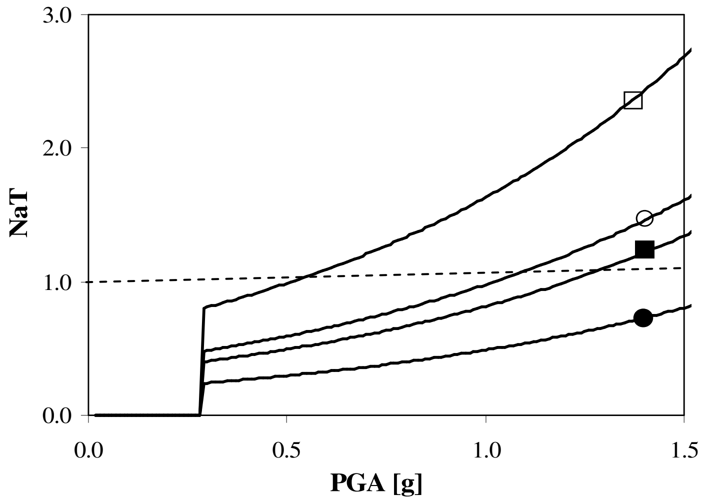

Figure 1: NaT_{emerg} for atmospheric, steel storage tank (anchored and unanchored, full) for two arrival times of seismic wave: 50 s (○: anchored; □: unanchored); 100 s (●: anchored; ■:·unanchored). τ_{action} = 30 s.

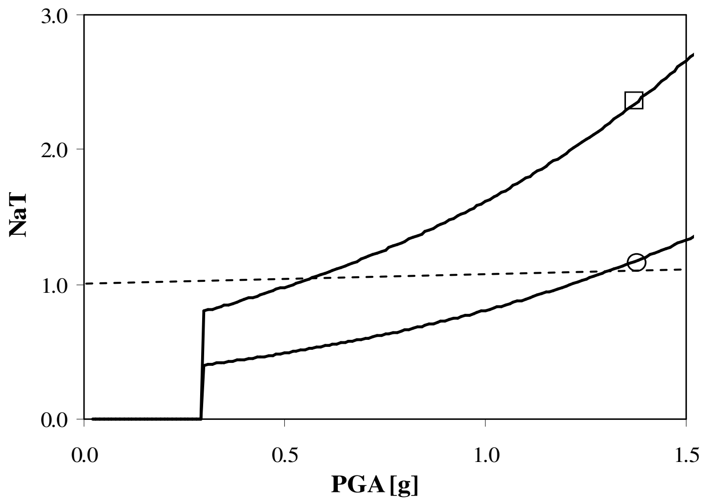

Figure 2: NaT_{emerg} for pressurized, horizontal steel storage tanks for two arrival times of seismic wave. □: 50 s; ○: 100 s. τ_{action} = 30 s.

5. Conclusions

With respect to Na-Tech risks, toxic dispersion is the main issues for people, wither for long or for short-term warning alarm. Early warning measures are clearly strongly effective for volcanic Na-Tech whereas the earthquake early warning can be essential for transportation system.

6. Acknowledgments

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7. References

Cruz, A.M., 2005, Natech Disasters: A Review of Practices, Lessons Learned and Future Research Needs, 5th Annual IIASA-DPRI Forum, 14-18 September. Beijing.

Cruz, A.M., L.J. Steinberg, A.L. Vetere-Arellano, J.P. Nordvik, and F. Pisano, 2004, State of the Art in Natech (Natural Hazard Triggering Technological Disasters) in Europe. DG Joint Research Centre, European Commission and United Nations International Strategy for Disaster Reduction, Ispra, Italy.

De Pinna, S., 1998, Forces and Motion, Austin, Texas: Raintree Steck-Vaughn Publishers.

DPC, 2001, Pianificazione Nazionale d'emergenza dell'area vesuviana: Proposta di aggiornamento. Dipartimento della Protezione Civile, Prefettura di Napoli, Napoli.

Hietaniemi, J. and E. Mikkola, 1997, Assessment and mitigation of the consequences of fires in chemical warehouses, VTT Research Note 1811.

Khan F.I. and S.A. Abbasi, 2000, Modelling and simulation of heavy gas dispersion on the basis of modifications in plume path theory, Journal of Hazardous Materials 30, 15-30.

Lindell, M.K. and R.W. Perry, 1996, Identifying and managing conjoint threats: Earthquake induced hazardous materials releases in the US. Journal of hazardous materials 50, 31-46.

Pauls, J.L., 1987, Calculating evacuation times for tall buildings, Fire Safety Journal, 120 213-235.

Salzano, E., B. Picozzi, S. Vaccaro and P. Ciambelli, 2003, The hazard of pressure tanks involved in fires, Industrial and Engineering Chemical Research 42,1804-1812.

Salzano, E., Di Carluccio, A., Garcia-Agreda, A., Fabbroci-no, G. & Manfredi, G. 2007, The Interaction of Earthquakes with Process Equipment in the Framework of Risk Assessment, American Institute of Chemical Engineers, 41th Loss Prevention Symposium, Houston, TX.

Salzano, E., Iervolino, I. & Fabbrocino, G. 2003. Seismic risk of atmospheric storage tanks in the framework of quantitative risk analysis, Journal of Loss Prevention in the Process Industry 16: 403–409.

Wright M.S., G.K. Cook and G.M.B. Webber, 2001, The effects of smoke on people's walking speeds using overhead lighting and wayguidance provision, Proceedings of the 2nd Int. Conference on Human Behaviour in Fires, MIT, Boston (MA).