Journal of Polish Safety and Reliability Association
Summer Safety and Reliability Seminars, Volume 4, Number 2, 2013

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Approaches to industrial risk assessment coupled with catastrophic natural phenomena

Keywords

Na-Tech risk, quantitative risk assessment, industrial facilities, natural hazards, chemical and process industries

Abstract

The aim of this contribution is to focus attention on a new emerging risk known in the literature as Na-Tech risk (Natural-Technological risk). Na-Tech are technological accidents triggered by natural events, these are of particular interest for high risk industries. The magnitude of such an event is much broader than that related to a technological accident and its management is much more complex. Adequate preparedness, proper emergency planning and effective response are crucial for the prevention and mitigation of the consequences of Na-Techs This contribution gives a general overview of the methodologies, that are currently being developed, in order to integrate these types of scenarios into the conventional quantitative risk analysis for chemical and process industry.

1. Introduction

Natural phenomena are often the indirect cause of technological accidents with severe consequences for humans and the environment, particularly in areas that are not prepared to cope with this type of emergency due to a land-use not properly planned. In the literature such an event is known as Na-Tech accident (Natural Technological accident) or simply Na-Tech. The increasing number of these events is leading scientists to orientate their research on the study of natural-technological risks.

A recent example of Na-Tech, which had an important media impact, was the accident involving the Fukushima (Japan) nuclear power stations, caused by an earthquake/tsunami in 2011. The damage was caused by the malfunction of the system pumping cooling water to the reactors [16]. The earthquake, that hit Japan, also caused a fire in the Chiba oil refinery.

Girgin reports on the Kocaeli earthquake of 1999 [12], which was a devastating disaster hitting one of the most industrialized regions of Turkey. Among the numerous Na-Techs that occurred, the author analysed incidental scenarios related to chemical industries, such as the massive fire at the TÜPRAŞ refinery in the Gulf of Izmit and the acrylonitrile spill at the AKSA acrylic fibre production plant.

Even modest natural events, in some cases, must not be underestimated. For example, as reported by many local newspapers, during floods that occurred in autumn and winter of the past four years (2008-2012), in Sicily (Italy), several refinery shutdowns were necessary to prevent and mitigate the damage due to the overloading of the water treatment lines, in some cases, resulting in soil and groundwater contamination.

This contribution focuses on Na-Tech related to the chemical and process industries. In this context, particular attention must be paid to high risk industries. Industries at high risk are those where the hazard is associated with the presence of hazardous substances in quantities exceeding the threshold limits established by specific laws (Seveso Directives [8]-[11]).

The magnitude of a Na-Tech is much broader than that of a natural event, furthermore its management is much more complex because the consequences of the release of hazardous substances aggravate those due to the natural disaster. Many Na-Tech accidents have led to fatalities, injuries, environmental pollution and economic losses [5], [18], [22], [38], [42]. A great concern is also related to other aspects, such as the potential overloading of the emergency response and/or the unavailability of many essential utilities (water, electricity, etc.).

As shown in [7], legislation and standards for chemical-accident prevention do not explicitly refer to Na-Techs. In order to cope with emergencies related to these events, in recent years, methodologies for risk assessment incorporating Na-Tech scenarios are being implemented. These approaches will be useful tools for a complete risk analysis, to prevent and/or mitigate negative consequences and, finally, also to plan and manage emergencies.

After a description of current legislations and past Na-Tech investigations, this contribution gives a general overview of the methodologies, that are currently being developed in order to include Na-Tech scenarios in the conventional quantitative risk analysis for the chemical and process industries. Thus the main object is to give the state of the art related to the approaches to industrial risk assessment coupled with catastrophic natural phenomena.

2. European legislation relevant to Na-Tech risk reduction

At the European level there is no specific law or any type of guidelines regarding Na-Tech risk assessment and management. However there are several laws indirectly mentioning Na-Techs, through the rules governing industrial establishments handling hazardous materials, landfill sites and waste treatment plants [7]. Also regulations for managing lifeline systems operations (such as electrical power plants, gas and oil pipelines, etc.) indirectly concern to Na-Tech risk reduction.

As mentioned in the introduction, the focus of this contribution is on chemical plants; the Seveso Directives specifically refer to the prevention of major accidents in the chemical industry [8]-[11]. Even if these laws do not include specific requirements for Na-Tech management, they indirectly address them. Indeed, the legislation calls for the analysis of “external events” which may lead to chemical releases, this obviously implies also the consideration of the potential threat of natural hazards. Nevertheless, these Directives do not indicate the methodologies or the actions to take with the aim of achieving these requirements, as a consequence the levels of response preparedness vary among European countries.

In this contest, a set of guidelines to help member states to accomplish this indirect requirement is given by [31], [10] and [4]. A summary of how various EU countries are currently facing to Na-Tech events is given in [7].

3. State of art on Na-Tech studies

The literature shows few studies on the analysis of Na-Tech risks, whereas several works are related to natural and technological disasters, as separate events. Also several surveys related to Na-Techs, that occurred in the past (in particular seismic Na-Techs), are given in the literature.

3.1. Na-Tech disasters

In *Table 1* some examples of the release of hazardous materials associated with a Na-Tech are given, as documented in journals, reports and web-sites. The list is obvious not exhaustive and the literature shows that there is limited data about some types of Na-Tech.

Some considerations come from reports given by the European Commission related to surveys of past accidents. These will be mentioned in the following section and their findings can be summarized as:

- Na-Techs are increasing;
- releases of hazardous substances is more likely to occur from larger facilities (this has been observed for earthquakes);
- damage is more likely to occur to older industrial facilities;
- Na-Techs are more frequent during earthquakes, followed by floods and storms.

3.2. Past surveys related to Na-Techs accidents and lessons learned

The first study on Na-Tech risks was due to Showalter and Myers in 1994 [36]. They made a survey to determine the number of technological emergencies triggered by natural disasters in the United States during the period 1980-1989. They found that the majority of Na-Tech incidents were triggered by earthquakes, followed by hurricanes, floods, lightning, winds and storms. Finally a trend towards an increasing number of Na-Techs during the period, analysed by the authors, was observed.

After the Northridge earthquake in California in 1994, Lindell and Perry [22] analysed the number of hazardous material releases caused by the earthquake. It was found that the release of dangerous substances occurred from the 19% of the industrial facilities in the state, thus the authors strongly recommended the assessment of the impact of these releases in seismic areas.

Table 1. Some examples of releases of hazardous material associated with a Na-Tech

Natural event	Location - Year	NaTech events	Ref.
Flood	Southeastern Idaho (US) - 1976	Releases of toxic substances, such as DDT, PCBs, etc., from three commercial facilities and storehouses.	[42]
Earthquake	Mexico City (Mexico) - 1985	Small release of natural gas and sulfurous compounds from leakages of gasoline tanks.	[42]
Earthquake	Whittier Narrows, California (US) - 1987	~1400 natural gas line breaks and 30 releases of hazardous materials (the largest release was of 2/3 of a 1 ton chlorine cylinder).	[42]
Earthquake	Loma Prieta, Northen California (US) - 1989	~400 natural gas line breaks and 300 releases of hazardous materials involving miscellaneous of toxicants (the largest was of 2000 pound of ammonia).	[42] [21]
Ash fallout	Anchorage, Alaska (US) - 1992	After the ash fallout due to the eruption of Mt. Spurr, although care was taken to minimize the entering of ash into wastewater treatments. An hard deposit was formed and, during the spring thaw, some local flooding occurred due to the blockages of pipes.	[15]
Flood	Midwest (US) - 1993	Releases of toxicants (benzene, toluene, lead, chromium, paints, solvents insecticides, etc.).	[42]
Earthquake	Northridge, California (US) - 1994	9 petroleum pipeline ruptures involving hazardous materials, ~750 natural gas line breaks, a huge release of sulphuric acid during a train derailment.	[42] [22]
Hurricane Mitch	Barrio of Istoca (Honduras) - 1998	Numerous barrels of pesticides involved.	[2]
Hurricane Georges	Pascagoula, Mississippi (US) - 1998	Sinking of floating roofs of storage tanks with releases of oil in some refineries.	[23]
Earthquake	Kocaeli (Turkey) - 1999	Several equipment losses from industrial facilities, two were noteworthy: the fire at the TÜPRAŞ refinery (Korfez) and the acrylonitrile spill at the AKSA acrylic fibres production plant (Ciftlikkoy).	[12] [38]
Hurricane Floyd	Eastern North Carolina (US) - 1999	Several releases from fuel oil and propane tanks; many municipal waste-treatment plants inundated.	[35]
Flood	Tookai, Nagoya (Japan) - 2000	Releases of chemicals from several industrial facilities	[7]
Heavy precipitation	Baia Mare (Romania) - 2000	The melting of the snow deposit over a pond filled with cyanide containing wastewater caused the increase of the pond level. A breach in the dam caused the escape of 100,000 m^3 of wastewater into the Lapus and Danube Rivers.	[7]
Lightening	Louisiana (US) - 2001	Fire on tanks in a refinery	[7]
Hurricane Katrina	Louisiana and Mississippi (US) - 2005	Loss of feedstock led to some onshore energy industry losses. Damage due to some leaks of hydrocarbon to the environment.	[23]
Earthquake	Wenchuan (China) - 2008	Numerous companies producing fertilisers affected.	[18]
Earthquake/ Tsunami	Fukushima (Japan) - 2011	Nuclear accidents and losses in the hydrocarbon processing industry	[23]

Cruz et al. in 2001 identified potential Na-Tech scenarios from petroleum refineries subject to hurricane, flooding and lightning [6]. They found that these phenomena could trigger multiple and simultaneous hazardous releases.

Steinberg and Cruz in 2004 [38] studied Na-Techs that occurred during the 1999 Turkey earthquake. They identified more than 21 releases of hazardous materials triggered by the natural phenomenon. Eight of these events resulted in major consequences and impacted outside the confines of the establishments, these required the evacuation of thousands of residents and resulted in the abandonment of search and rescue operations for earthquake victims. The authors concluded that risk management and emergency response planning for such accidents are not sufficient since it is necessary to take into account that the natural phenomenon may cause: the simultaneous loss of electrical power and water, the failures of mitigation systems, the impediment of emergency responses, the potential simultaneous occurrence of numerous releases of hazardous substances, etc. Steinberg and Cruz also found that the likelihood of Na-Techs triggered by earthquakes increases with the amount of chemicals stored in the facilities. It is important to take this finding into account since there is the tendency to have fewer and larger facilities, thus handling larger volumes of dangerous substances.

It is worth mentioning that there are only a few works investigating the effects on structures caused by volcanic eruptions. The work of Rasà et al. [32] describes, from a qualitative point of view, various effects associated with volcanic ash fallout from Etna on buildings, electric motors and other systems. There are also few studies concerning damages and malfunctions of industrial facilities located in the territory surrounding a volcano. Recently, Baxter et al. [3] and Scandone [34] have analysed the reduction of water treatment (either industrial or civil installations) and accidents related to the transport of hazardous materials due to slippery road conditions.

3.3. Evolution of approaches to the analysis of Na-Techs

Na-Tech risks differ from technological or natural risks due their complex nature, a multi-disciplinary approach is required both for risk assessment and management.

The multidisciplinary nature of the problem can be understood from the scheme of the Na-Tech phenomenon given in *Figure 1*.

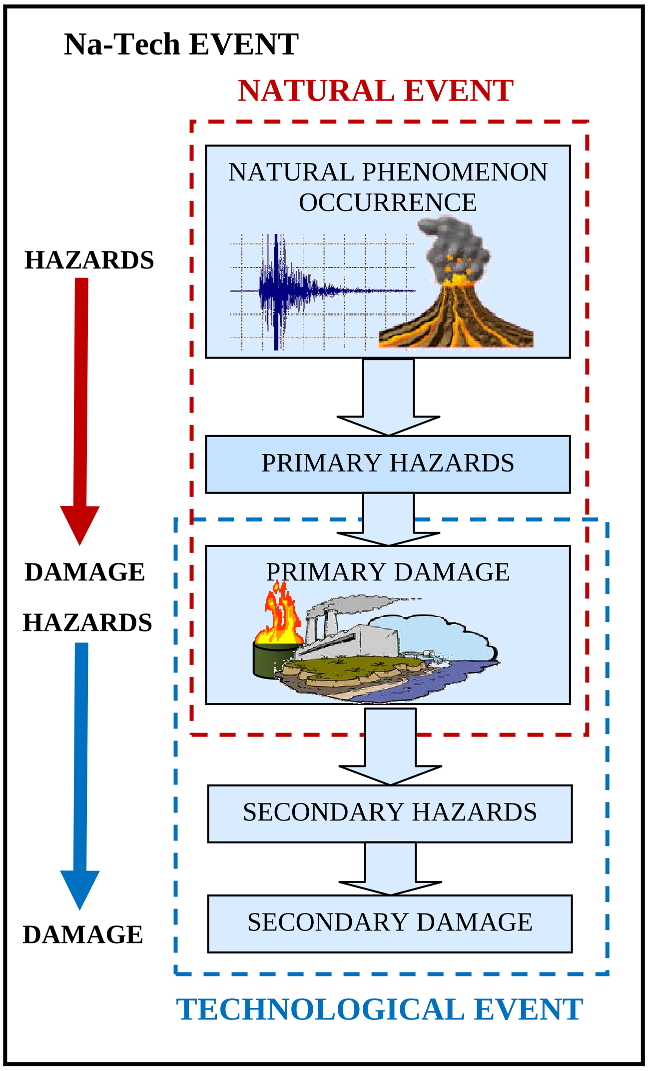

Figure 1. Schematization the Na-Tech phenomenon

The occurrence of a given natural phenomenon (earthquake, volcanic eruption, etc.) generates some secondary phenomena, which are indicated as "primary hazard", e.g. shaking, liquefaction, tsunami, land sliding, etc., in case of an earthquake occurrence, or lava flow, ash emission, tsunami, etc., in case of a volcanic eruption. The "primary hazard", in turn, generates an impact vector, whose entity is measured by a given physical parameter, e.g. the peak ground acceleration, for shaking caused by earthquakes, or the load of solid material, for ash emission caused by an eruption, etc. The impact vector causes the damage on a given target located in the surroundings (people, environment, civil and industrial structures, infrastructure, etc.) and also on the economy. Since this paper is focused on the study of Na-Tech events, the targets are industrial structures where hazardous substances are handled. The damage to the equipment is indicated as "primary damage" and causes the release of chemicals, representing the "secondary hazard" or “industrial hazard". The release of the substances evolves into a number of accidental scenarios, such as fires, explosions and toxic dispersions, depending on the substance. The "secondary hazard" generates another impact vector causing additional damages or making more severe the "primary damage".

A consideration, emerging from the investigations carried out by many researchers, is that common practises for risk assessment (e.g. the Purple Book approach [39]) need to be extended to take into account the characteristics of Na-Tech scenarios.

Antonioni [1] presented a general procedure for the implementation of Na-Tech scenarios in the standard Quantitative Risk Assessment (QRA) approach. *Figure 2* shows the flow-chart for the extended QRA. It only requires the modification of a limited number of conventional steps of QRA, these are:

- the development of specific damage models to estimate the probability and extent of equipment damage caused by a natural event;
- the definition of a specific procedure to account for the possibility of simultaneous releases.

In order to achieve the modifications of these formal steps, the starting point is the characterisation of the natural hazard(s) at the site where the industrial facility is located. Natural phenomenon characterization means estimating its frequency of occurrence and magnitude, some reference scenarios usually are identified.

The expected frequency is derived from historical data. In this context, the return period is an estimate of the likelihood of occurrence of an event. It is a statistical measurement denoting the average recurrence interval over an extended period. Assuming that the probability of the occurrence does not vary over time and is independent of past events, the theoretical return period is the inverse of the expected number of occurrences in a year. It is computed from a set of data (the observations) choosing an idealized distribution as indicated by Woo [41]. The estimation of expected frequency sometimes is not possible, for example Milazzo et al. analysed Na-Techs triggered by volcanic ash fallout from Mt. Etna (Italy) and evidenced that any statistical analysis, to achieve the expected frequency of the natural phenomenon, is speculative because of a variation of the eruptive style of the volcano over the years [28].

The magnitude is expressed by an intensity variable (destructive potential), which causes the damage when the interaction with the facility occurs. *Table 2* gives a list of the intensity variables for some natural events. The results of the characterization will be used to analyze the susceptibility of the equipment containing hazardous substances to be damaged due to the natural phenomenon (also called fragility or vulnerability).

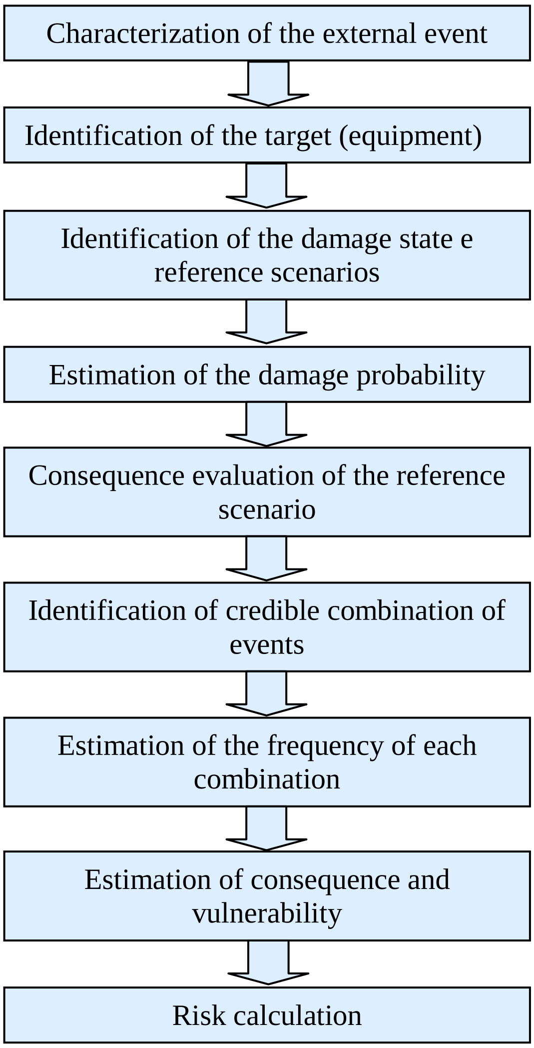

Figure 2. Flow-chart for the extended QRA

Table 2. Intensity variable for natural phenomena

Natural phenomenon	Intensity variable
earthquake	peak ground acceleration (PGA) or spectral displacement
flood	water height and/or water speed
lightening	flash density
volcanic ash fallout	ash load or ash concentration in the air
heavy precipitation	water height snow load

4. Current approaches to the risk analysis of Na-Techs

This section provides a review of methodologies, currently being developed, for integrating Na-Tech scenarios into the conventional risk analysis. These methods can be divided into:

1. simplified approaches (mainly used for an equipment risk ranking);
2. deterministic approaches;
3. probabilistic approaches.

4.1. Simplified approaches

Given the complexity of the QRA, simplified approaches specific to Na-Tech risk analysis have been developed to allow the classification of the vulnerability of chemical industrial equipment. These methods can be used for a preliminary analysis and are also useful for the design and to prevent and/or mitigate the consequences of Na-Tech events.

An example of a simplified method is mentioned in [17], it has been proposed in the framework of the iNTegr-Risk project. It is based on an hazard classification both for the natural phenomenon and the chemical facility under the impact of the natural event. Natural hazard are classified using specific values of the intensity variable for the natural scenario (*Table 2*). The natural-technological hazard indexes are defined based on the entity of damage, operating conditions and hazardousness of the handling substances. Data for the equipment classification are derived by a detailed analysis of literature related to Na-Techs. Four levels of natural-technological hazard are defined, as shown in *Table 3*.

Table 3. Natural-technological classification

Natural-technological hazard index	Classification
1	Very low
2	Low
3	Moderate
4	High

4.2. Deterministic approaches

A deterministic approach consists in defining a number of scenarios related to the natural event on which the hazard evaluation will be applied. Each scenario consists in postulating the occurrence of an event of a certain size occurring at a specified location. A typical deterministic analysis can be described in the four steps shown in *Figure 3*.

The first step is the identification and characterization of all natural events at the site, this includes the definition of the intensity variable of each event (*Table 2*). Next the distance between the source and each industrial site of interest must be measured. In the third step the "controlling event", i.e. the event that is expected to produce the strongest magnitude, has to be selected. Finally a threshold value for the intensity variable, causing specific damage to a given equipment, is defined.

Using the deterministic approach, it can be stated that the equipment undergoes a certain damage if the intensity variable exceeds the related threshold limit; if this value is not exceeded, the reference damage does not occur.

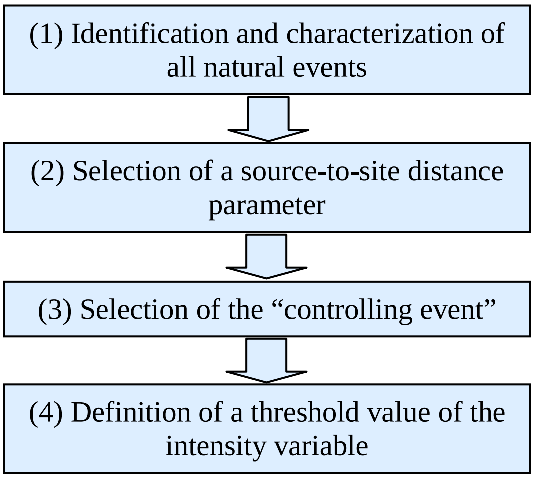

Figure 3. Flow-chart for a deterministic analysis.

An application of the deterministic approach is given below with respect to an oil storage area located in a seismic site:

- *Step 1*. The analysis starts with the identification and characterization of all earthquake sources capable of producing significant ground motion at the site, thus the magnitude of each earthquake is defined.
- *Step 2*. The distance between the source and the location of each facility is measured (*Figure 4*). It is expressed as the distance from the epicentre (D_e) or it could be also given as distance from the hypocentre (D_h).
- *Step 3*. The earthquake expected to produce the strongest magnitude (controlling event) is selected. Levels of magnitude, identified in step (1), are generally assumed to occur at the distances identified in step (2). The hazard at the site may be expressed in terms of the peak ground acceleration (PGA) obtained by means of predictive relationships (attenuation function).
- *Step 4*. The threshold values of PGA, causing specific damage, are defined in *Table 4*, as suggested in [33]; these values have been used for anchored atmospheric oil storage tanks.

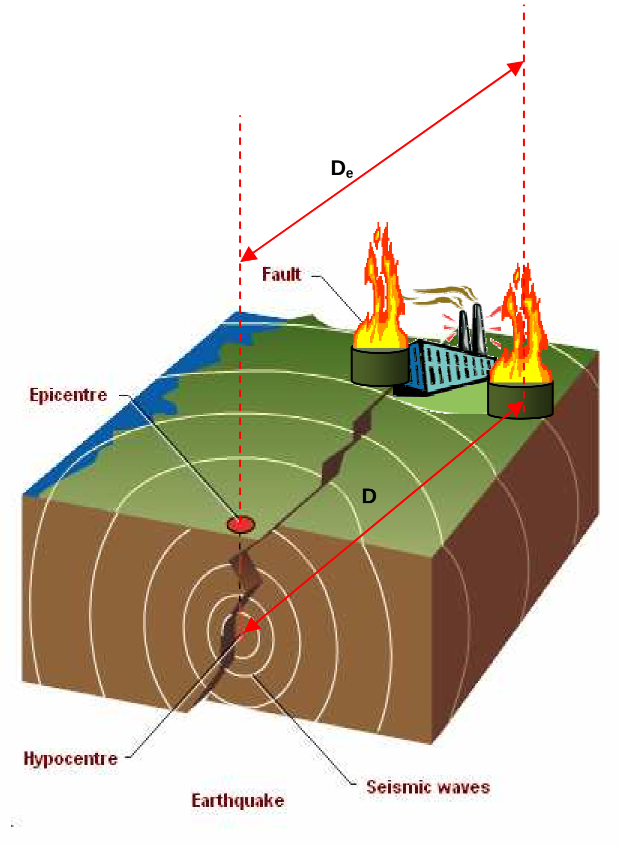

Figure 4. Source-to-site distance parameter selection

Table 4. Threshold value of PGA for anchored atmospheric storage tanks [33]

Damage	Filling (%)	PGA (g)
Negligible structural damage	≥ 50	< 0.935
	≅ 100	< 0.075
Low structural damage	≥ 50	0.370
	≅ 100	0.170
High structural damage	≥ 50	0.580
	≅ 100	0.120
Catastrophic structural damage	≥ 50	0.660
	≅ 100	0.395

If seismic risk is concerned, as in the case-study, the deterministic approach is based on the maximum “credible” intensity of earthquakes causing the damage on the equipment and a conservative estimate (worst-case scenario) for the subsequent accidental scenario triggered by the shaking and resulting in a loss of hazardous material or energy.
The deterministic procedure appears to be very simple. It provides a straightforward framework for evaluation of worst-case, when it is applied to structures for which failure could have extremely catastrophic consequences. However, it provides no information on the likelihood of occurrence of the “controlling event” and about the uncertainties related to the various steps of the analysis.

4.3. Probabilistic approaches

A probabilistic formulation is fundamental to the scientific understanding of Na-Techs. It is the basis of the computational models of the quantitative risk assessment. As mentioned above, the conventional QRA needs to be implemented as shown in *Figure 2*, this calls for the probabilistic formulation both for the natural phenomenon and the vulnerability of the equipment.
Concerning the natural phenomenon, probabilistic models must be defined for the description of the random variables which govern its occurrence (when possible) and severity. Only a few variables (intensity variables), encountered in the study of natural hazards and associated with the severity, can be precisely determined by observation, most variables are uncertainty, which reflect just the stochastic dynamics of the underlying processes, but also the partial and imprecise knowledge available about them at any given time. To model them in a satisfactory way which accommodates the prevailing state of uncertainty, one must adopt a suitable probabilistic description. For a variable X that takes continuous values x, a probability density function (p.d.f.), $f(x)$, is defined, such that the probability of the parameter falls between the upper value x_U and the lower value x_L. It is convenient to use one of the many standard probability distributions, which are well defined by relatively few parameters. The common distributions have evolved over centuries to represent a diverse set of random variables. In [41], brief descriptions of these common distributions are provided.
The probabilistic formulation of the natural phenomenon consists of the steps shown in *Figure 5*.

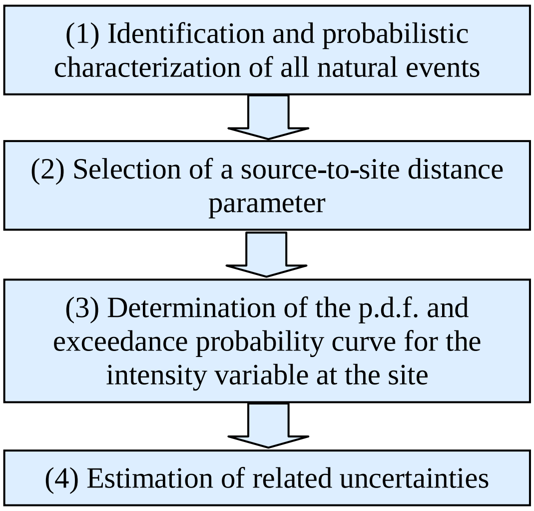

Figure 5. Flow-chart for a probabilistic formulation of the natural phenomenon.

An example, explaining how to perform the probabilistic formulation for the natural phenomenon, is given below. It refers again to the case-study mentioned above.

- *Step 1*. The earthquake sources are identified and characterized, this means that the probability distribution of the potential locations of the events must be defined (using for example the earthquake catalogue). In this example, uniform probability distributions have been assigned to each source, implying that earthquakes are equally likely to occur at any point.
- *Step 2*. The probability distributions defined in step (1) are combined with the source geometry to obtain the corresponding probability distribution of source-to-site distance.
- *Step 3*. The ground motion (intensity variable), produced at the site by earthquakes of any possible severity occurring at any possible point, is determined by means of predictive relationships (attenuation) [37]. The probability density functions of the PGA for each earthquake's magnitude are derived and, then, also the related exceedance probability curves (hazard curve) are defined. *Figure 6(a)* shows the probability density function (p.d.f.) of the peak ground motion (PGA) at the site, in this case a log-normal distribution has been used (a median PGA of 0.3 g and a standard deviation of 0.6 are assumed). The exceedance probability curve gives the average rate at which an earthquake of a certain magnitude will produce a PGA exceeding specific values. *Figure 6(b)* shows an hazard curve for the case-study, it refers to an hypothetical earthquake of magnitude M = 7.5 with an average recurrence interval of 500 yr at 20 km from the epicentre.
- *Step 4*. The uncertainties in earthquake location and magnitude and, also, those in ground motion parameter prediction must be estimated.

models estimating the entity and probability of the equipment damage caused by a natural event. Firstly the modelling of the natural phenomenon' effects has to be completed, then, the conversion of these results in consequences for a given industrial facility is required. This can be done by the so-called "vulnerability analysis", which is described in the literature related to the estimation of the consequences for people due to an industrial accident causing scenarios, such as fires, explosions or toxic dispersions [39]-[40]. In this case, a function correlating the magnitude of the impact (intensity variable) with the extent of damage caused by the natural event is derived (fragility), i.e. a relationship between the dose and the response. In risk analysis, a method commonly used is the "Probit analysis", which relates the Probit variable (*Y*) to the probability (*P*). In this case, the Probit variable measures the percentage of equipment of the same type that, under the impact of a natural phenomenon with a given intensity of the physical parameter (*V*), will undergo a certain damage. This variable follows a normal distribution, with an average value of 5 and a standard deviation of 1. The relationship between the Probit variable and the probability (given by (1)), was derived by Finney in 1971 [20]:

$$P = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Y=5} \exp\left(-\frac{V^2}{2}\right) dV \tag{1}$$

the equation (2) is normally used to calculate the value of Y

$$Y = a + b \cdot \ln V \tag{2}$$

where a and b are constants, which are experimentally determined from a data set of accidents. V is a measure of the intensity of the damaging effect (physical parameter).

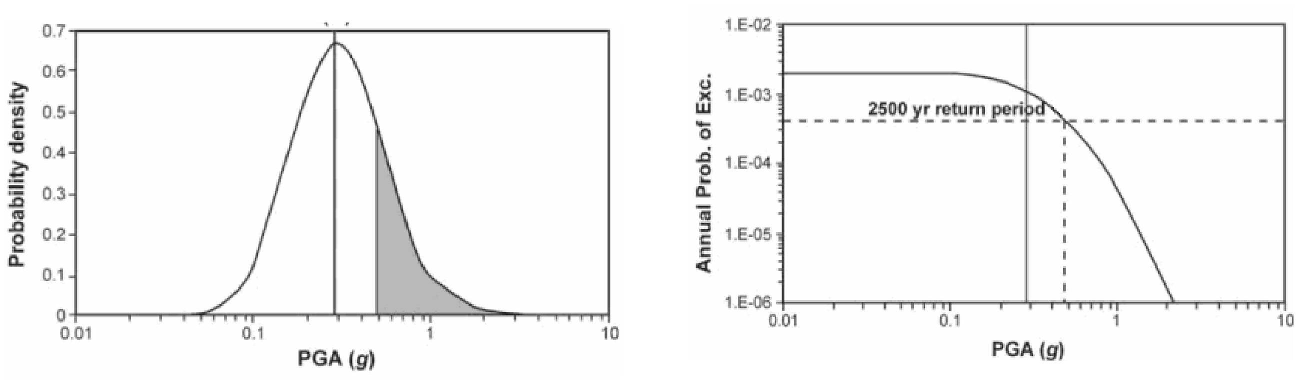

Figure 6. (a) Probability distribution function of PGA; (b) Exceedance probability curve (the return period is the inverse of the annual probability of exceedance)

roofs located in an area prone to earthquakes. Firstly, a number of potential failures for the facility must be chosen. According to HAZUS damage classification (1997) [14], the following classes describe the behaviour of atmospheric steel tanks subjected to earthquakes:

- DS1 absence of damage;
- DS2 slight damages to structures;
- DS3 moderate damages;
- DS4 extensive damages;
- DS5 total collapse of structure.

An observational approach may be used to allows the development of fragility relationships. This approach is based on the use the damage states DS of HAZUS and a data set reporting the damage analysis for a set of storage tanks (e.g. from earthquake in Northridge [22]). The trend of the "fragility curves", representing the probability of getting specific damage states DS, is shown in *Figure 7*.

Then, Probit relationships giving the probability of damage with respect to PGA could also be derived as given in [20]. Also uncertainties must be estimated, to this purpose some indications are given in [24].

Simplified equipment damage models suitable for use within a QRA framework were developed or are under development, partly based on the analysis of past accident data of earthquakes, floods and lightening (see [19], [30], [33]). Additional contributions concern the effects of volcanic ash fallout on atmospheric storage tanks and filtration systems, these are reported in [25] and [26].

The results, given in [25] and [26], have been used in a simplified approach for the vulnerability mapping of industrial facilities (see [27]). This procedure can be summarized in the flow-chart of *Figure 8*. According to this approach, the first step is the definition of a specific volcanic phenomenon and the identification of a vulnerable system at a given location around the volcanic crater. Hence, it is necessary to define the potential failure for the system with respect to the intensity variable. Afterwards, either the threshold value and the exceedance probability of this limit must be calculated (using the exceedance probability curve at the location of the facility). Finally, an appropriate procedure has to be selected to interpolate exceedance probability data related to a set of locations of the territory, in order to represent the vulnerability of the system on a cartography using a

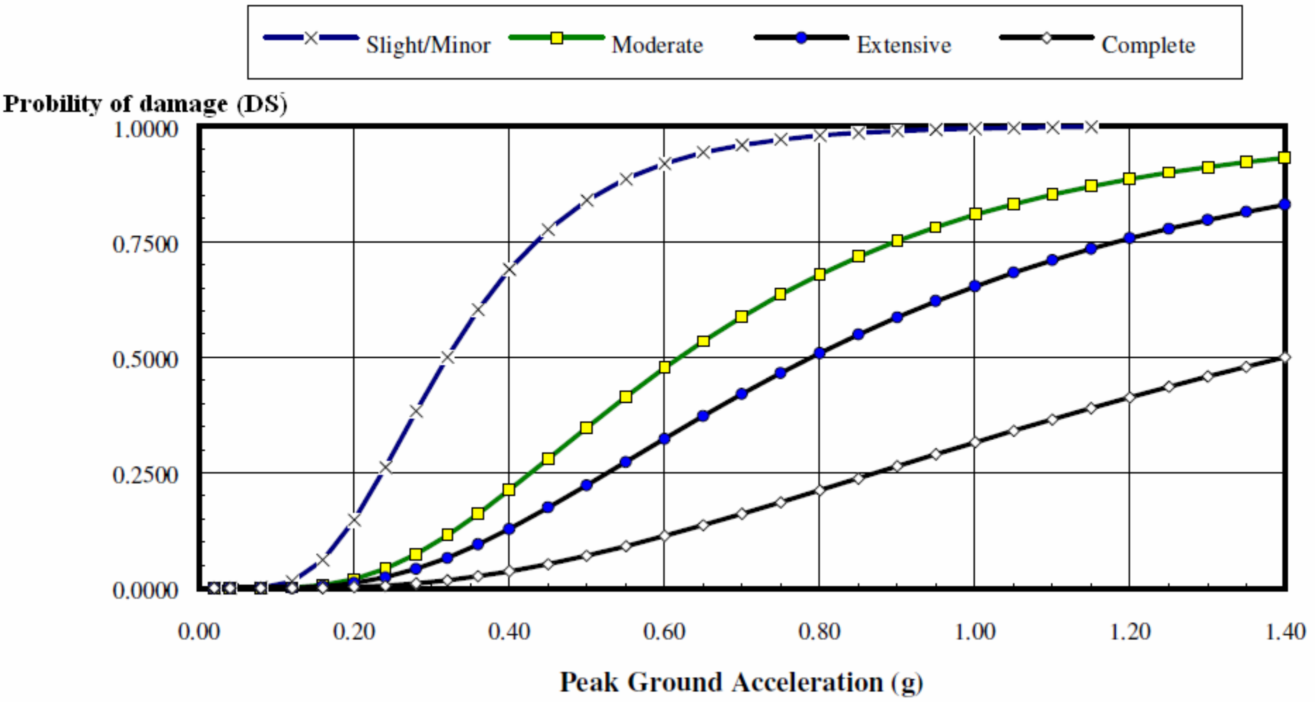

Figure 7. Typical fragility curves for the various damage states of HAZUS

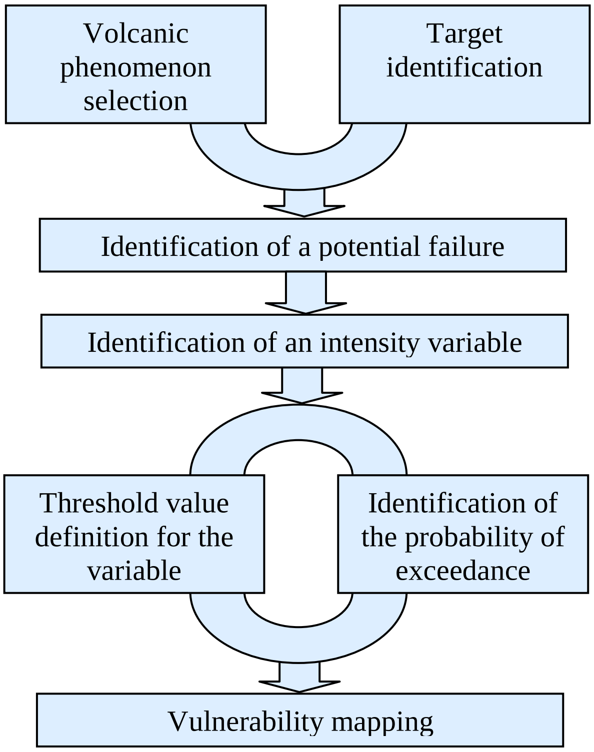

Figure 8. Flow-chart for the vulnerability mapping.

Figure 9 shows an example of vulnerability map [27] related to the light damage of fixed roof storage tanks due the phenomenon of volcanic ash fallout.

This simplified procedure has been developed in the framework of a project PRIN 2008 funded by the Italian Minister (MIUR).

5. Conclusions

The analysis of the state of the art related to the approaches to industrial risk assessment coupled with catastrophic natural phenomena shows that few methodologies assessing Na-Tech risks exist. Given the findings of many researchers, that (1) Na-Techs are increasing and (2) those, often, cause releases of great amount of hazardous substances, it is strongly recommended the analysis of potential industrial accidents triggered by natural phenomena and the development/consolidation of tools to achieve this aim.
In this context the main efforts have been dedicated to the implementation of the Quantitative Risk Analysis (QRA) through different levels of complexity:

- *Level* 1: simplified approaches;
- *Level 2*: deterministic approaches;
- *Level 3*: probabilistic approaches.

The level of the analysis to be used depends on the scope of the study.

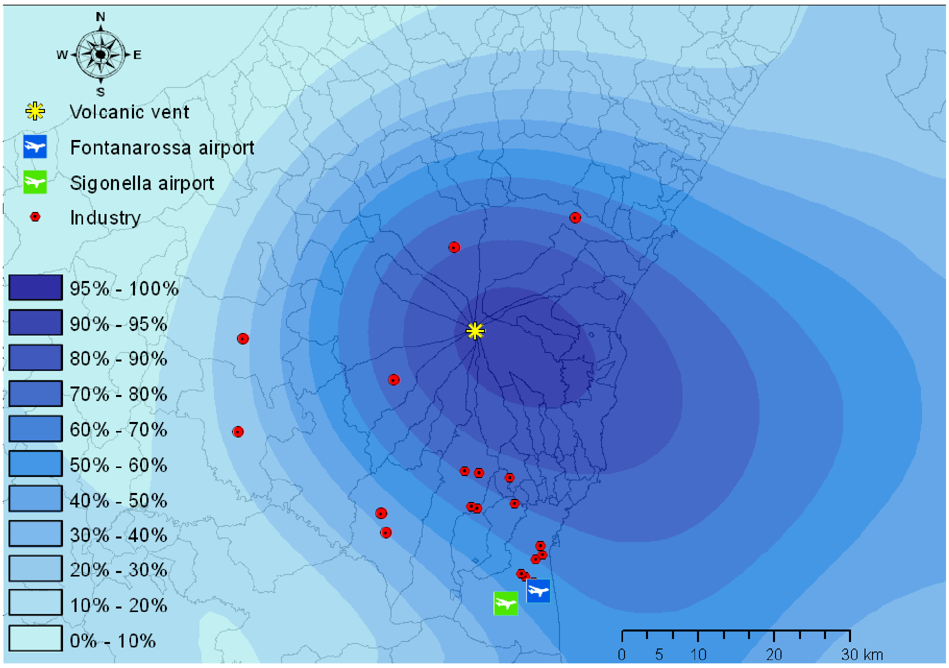

Figure 9. Vulnerability mapping for light damage of atmospheric fixed roof storage tanks

The basis for the integration of Na-Techs in QRA regards the development of specific damage models for the estimation of the magnitude and likelihood of damage to facilities due to natural phenomena.

In this context, the development of vulnerability models, interfaced with a Geographic Information System (GIS) software makes more efficient the management of data for the risk calculation and also more effective the planning and management of emergencies.

It has been seen that the greatest concern of Na-Techs is related to the potential overloading of the emergency response system and its ability to minimize losses to persons and property. More specifically, technological accidents may be triggered by natural events and their effects may add to or worsen the condition of people and environment struggling with the effects of the natural event. Safety and rescue operations may be impeded by the shortage of resources (water, energy, etc.) or by the reduction of accessibility due to debris and the fleeing population. In this context, as suggested in [27], an interactive GIS interface of the vulnerability maps helps to identify available refuges, escape paths, etc; it is also important, as reported in [1], to define a specific procedure to take into account the possibility of more releases of hazardous substances from multiple facilities.

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