Structural Reliability Issues in Na-Tech Risk Assessment

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Abstract

Technological accidents caused by natural events like hurricanes, earthquakes, flood, lightning are known as Na-Tech events. In case of chemical installations most of the failures in such events are directly related to structural damages. What differs accidents initiated by extreme meteorological conditions from the others is the fact that both natural disasters and technological accident occur at the same time and this very often leads to the failures of many elements in one or more installations. Therefore the risk assessment for Na-Tech accidents should be performed in a proper way, taking into account this specific situation. In Poland within the national strategic programme dealing with the development of informatics system of country protection against extreme natural events, one of the projects is devoted to the risk assessment of major industrial accidents triggered by natural phenomena. The paper discusses the methodology for risk assessment for Na-Tech events applied in the implementation in this project.

Keywords: extreme natural events, technological hazard

1. Introduction

Natural hazard and disasters are one of the sources of the risk for chemical installations and critical infrastructure as refineries, processing plants, pipelines or fuel storages. Chemical accidents caused by natural events, like flood, hurricanes, lightning or earthquakes are generally known under the name Na-Tech [6,7,10,11,15,16]. Na-Tech events can happen all over the world, leading to fatalities, injuries, damages, contamination of environment and essential economic consequences. One of the main problems of the most Na-Tech accidents is the appearance of both natural disaster and technological accident simultaneously. Additionally it should be taken into account that the damages can happen in one or many elements of the chemical installations, or at the same time in different installations on the area where extreme natural phenomena have happened.

In Poland, within a national strategic programme on the development of IT system of country protection against extreme natural events (ISOK), one of the projects has been devoted to the risk assessment of major industrial accidents triggered by natural events. The main aims of this project are the following:

- to estimate the probabilities of major industrial accidents and possible consequences basing on the frequency of the occurrence of extreme natural events,
- to provide in real time analysis of the possible accidents that can be triggered by natural events, basing on the routine numerical weather forecast.

The frequency of the appearance of extreme natural events has been determined using the information from meteorological synoptic stations. The total duration of collecting measurements at synoptic stations in Poland is more than 60 years, which means that relatively good statistics exists for the purpose of the project.
Within the ISOK system more than 1100 chemical installations are considered – from which about 150 is of the Seveso type. The installations are characterized by the dangerous substances, which are the main source of hazard and the type of activity (processing plant, storage, pipeline, transportation, etc). In order to assess what kinds of situations leading to major accidents can be triggered by natural events one needs to apply relevant methodology for the risk assessment of Na-Tech events. It is quite obvious, however that the most of Na-Tech events are strictly related to structural damages, hence there is a link between Na-Tech events and structural reliability. In the following sections we describe the methodology of risk assessment of Na-Tech events and possible releases of dangerous substances in Na-Tech events. Finally the application of the presented methodology to the implementation of ISOK project is commented.

2. Assessment of industrial risk caused by Na-Tech events

The general procedure recently accepted for the assessment of industrial risk caused by natural events consists of the following steps [1]:
(1) Characterization of the external event;
(2) Identification of vulnerable equipment;
(3) Identification of damage states for reference scenarios;
(4) Estimation of the damage probability given the impact;
(5) Consequence evaluation of the selected scenarios;
(6) Identification of credible combinations of events;
(7) Probability calculation for each combination;
(8) Consequence calculation for each combination;
(9) Calculation of risk indexes.
The first step is the analysis of natural hazards at the localization of the installation. At this stage it is important to characterize the frequency and intensity of natural events – usually by rather simple approach, often applied in the risk analysis. First of all a limited number of the "reference events" should be identified with the duration of such events. This allows for the determination of impact vector – the elements of this vector are the selected parameters characterizing the intensity of natural event. It should be added that in this step no data are produced for detailed structural analysis of the installation – the main aim is to provide input data for simplified models of installation damages.
In the second step the target elements of installation have to be identified. The critical elements of the installation are those having some potential for causing major accident in case of the exposition to natural event. The intensity of the scenario triggered by natural event depends on the reaction of the installation and the properties of dangerous substance in the plant. One should take into account: operational conditions, size of the installation, shutdown system and safety features. For different types of elements expected maximal possible damages due to cracks have to be found.
In the third step all damage states related to the critical reference elements of the installation (that have been found in the previous step) should be identified. The definitions of damage states (DS) are used for determining to what extent the loss of the integrity of the containment can happen. The application of event tree method and taking into account the properties of the substance released allows for the identification of the reference scenarios, which can be linked to damage states.

In the fourth step basing on the identified damage states one can estimate the probabilities of damages using simplified models for determining vulnerability and weak point of the installation. These models use the parameters characterizing the intensity of natural events introduced in the first step.

The development of simplified models for the determination of the damages of the elements of the installation in QRA is a specific issue necessary for the implementation of the methodology. Quite often observational models based on the past accidents are used. The consequence analysis (i.e. the fifth step) for the reference scenarios identified in the third step, can be performed by applying such models. It should be stressed, here that more than one scenario can take place at the same time due to the fact that more than one element of the installation can fail.

This means that three additional steps must be considered:

- identification of credible combination of events – step (6), then
- calculation of their frequencies – step (7), and
- estimation of the consequences for each likely combination of the reference releases – step (8).

In this methodology it is taken into account that a number of simultaneous scenarios can take place and all of them are initiated by the same natural phenomena. Then the sum of vulnerabilities determined for each scenario is considered as a representation of all concurrent scenarios and thus allowing for determining the risk indices, which is the last ninth step.

In paper [1] vulnerability ranking of the elements of installation has been also proposed. This is very important in emergency planning and for the activities related to the mitigation of the consequences of accidents.

It should be also noted, that he credible scenarios identified as a possible consequence of natural events impact are associated to the different storage or operating conditions. The four following categories of storage and process equipment can be defined, having a progressively increasing hold-up: 1) reactors and heat exchangers; 2) columns; 3) piping; 4) vessels (process and storage).

Similar approach has been used to make vulnerability ranking of typical elements of the installations, both processing plants and storage facilities [1]. Several categories of critical installation elements have been identified and associated to natural events, basing on the degree of the damage of these elements, exploitation conditions and possible consequences in case of the release of dangerous substance. The ranking proposed in [1] for Na-Tech events uses technical material available in [3,4,9,12,14,17].

In order to make this ranking reliable, an important part of the procedure is the assessment of the consequences of possible releases in Na-Tech events, which is described in the following section.

3. Possible releases of dangerous substances in Na-Tech events

In case of Na-Tech events probably the most dangerous situations can happen in case of extreme meteorological conditions related to the occurrence of strong winds, hurricanes, tornadoes, lightning and earthquakes.

The releases of chemical substances in industrial installations can have different forms: leakages, emissions of toxic or flammable material to atmosphere or fires and explosions. On Fig. 1 basic scenarios are presented – they depend on the properties of chemical substance (toxicity, density, flammability), the amount of the released material, how the substance is stored or processed and on meteorological conditions during the accident. The leakages from the vessels under atmospheric pressure, pipes or joints containing flammable substances can further lead to the ignition (for example due to lightning) and finally to fires or explosions.

The emissions to atmosphere can happen when toxic or flammable material is released from the vessels or the elements close to them (like valves, pipes, etc). Toxic substances can be stored both under atmospheric pressure and in pressurized vessels. In both cases a cloud of toxic substances is formed and can be further dispersed within and outside of the installation what, in particular for populated areas can cause severe consequences for human health and environment. During rainstorm, if the substance is water-soluble this can lead to the corrosion of the material. Flammable substances can be also stored in pressurized or atmospheric vessels. After the release from pressurized vessel a pool can be formed, then substance can evaporate or a pool burning occurs. During the evaporation a cloud is formed, what, in case of the occurrence of the ignition, leads to the events known as vapour cloud expansion (VCE), which very often have serious consequences [5].

The release of one chemical substance can initiate successive other events. If the ignition of flammable liquid takes place or some other strong source of heat provides enough large amount of heat energy close to pressurized vessels contacting liquid gas (like propane) then there will be a potential for BLEVE (boiling liquid evaporating vapour explosion) event [2]. Furthermore after BLEVE a blast of compressed air can occur due to the sudden release of compressed vapour and liquid.

If the ignition occurs immediately in the substance of the pressurized vessel then fireball can be formed. This is possible in case of the occurrence of the stream with high momentum when the vessel is damaged. Fireball can move in the air even up to few hundred meters which makes potentially very dangerous situation in surrounding places. One should also add that in case of BLEVE the fragments of the vessel can be thrown out even on longer distances than fireball.

Flammable liquid gases released during explosion but without the ignition can cause the expansion of vapour in the line of wind direction.

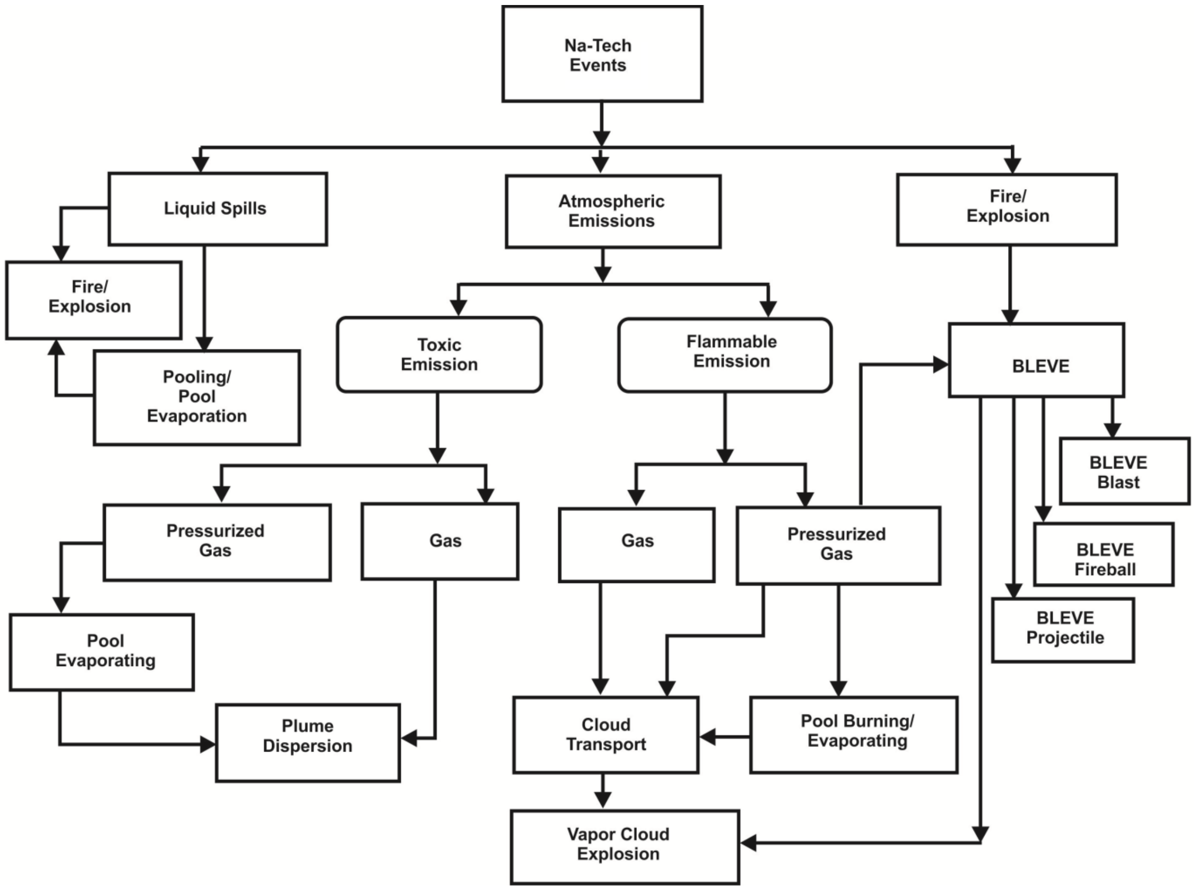

Fig. 1. Accident scenarios initiated by meteorological events (adapted from [8]).

In paper [1] statistical analysis has been performed based on 272 cases related to the occurrence of flood. This analysis can be summarized by stating that pipelines and vessels (atmospheric and pressurized) are the elements which are the most exposed in dangerous situations caused by the flood. This seems quite natural because the way how the substance is stored or transported, in case of the damages of the containment, cause the failure of these elements leading to accident scenarios with severe consequences. It is quite evident that atmospheric vessels are more vulnerable than the pressurized ones. In fact when the water reaches the level exceeding some threshold it is absolutely sufficient to cause the break of the containment or drifting the vessel, while for pressurized vessels a really strong stream is needed to destroy its foundation.

This section can be summarized as follows:

1. The most dangerous Na-Tech events are initiated by wind, lightning, earthquake and flood.
2. The elements of chemical plants which are the most exposed to the extreme meteorological events are: vessels, pipes and pipelines. Almost all negative effects are strictly related to structural damages.

4. Application to the ISOK system

As it has been already mentioned the main aims of one of the projects being implemented in Poland under the ISOK system are strictly related to the risk assessment of Na-Tech accidents. Therefore the methodology presented in previous sections can be almost directly applied in the project. Nevertheless some important issues have to be underlined:

a) In case of the Seveso plants the information of possible accidents triggered by natural phenomena can be, in principle, borrowed from safety reports. In particular for big installation the risk analyses contain a lot of useful data and the almost ready scenarios can be implemented in data bases of the ISOK system.
b) For smaller installations there is a need to performed a simplified analysis of possible hazard sources. It has been decided to prepare a special questionnaire containing the most important question on the installation type, dangerous substance, localization, etc. Basing on the answers one can categorize these installations taking into account:
    - The type of possible accident (toxic release, fire, explosion) and its consequences.
    - The vulnerability to extreme meteorological factors.
c) While there is relatively good statistics of meteorological data there is only small number of accidents reported as triggered by natural events. Hence in the fourth and fifth step of the methodology described in section 2 no observational models can be really applied and at least a simple analysis of "what-if" kind has to be done first. Therefore this problem is also raised in the questionnaire.
d) The process of gathering information from chemical installations should be continuous, therefore a special legal procedure for this purpose is highly recommended.

An important feature of the ISOK system is that – apart from the risk assessment based on statistics data – the system should operate routinely providing alerts on possible occurrence of extreme weather conditions basing on the current weather forecast. Every 6 hours when new weather forecast comes, the system will check if there is a chance of extreme meteorological phenomena and in such a case automatically all the installations possibly vulnerable to these events, will be analysed. Then the system will generate on the map hazardous zones for the

reference scenarios related to meteorological factor, which can initiate the Na-Tech accident for this installation.
This information will be available for national services: police and fire brigades (which play the role of civil defence in Poland).
Although the system is devoted to chemical plants the same procedure can be applied also for nuclear installations.

5. Conclusions

The question of structural reliability plays an important role for chemical accidents initiated by extreme natural phenomena. A dedicated methodology for the risk assessment of Na-Tech events proposed in [1] can be implemented in practice, however some modifications related to the estimation of probabilities and consequence analysis have to be done. One of the problems is related to rather poor statistics of Na-Tech events, therefore additional simplified analysis have to be performed. Collection of all relevant data from industrial installations must be done in order to ensure reliability of such analysis.
The methodology can be also applied in operational systems aiming at producing in real-time alert information on possible occurrence of the conditions for Na-Tech accidents, basing on current weather forecast. This demands computing capacities enabling enough fast processing of information as new weather forecast is available. Such project has been started in Poland within the national strategic programme ISOK devoted to the protection of the country against extreme natural events.

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