BABEȘ-BOLYAI UNIVERSITY
FACULTY OF ENVIRONMENTAL SCIENCE AND ENGINEERING

Integrated Approach of NaTech Risk in Areas of Natural Gas Transmission Activities that are prone to Land Instability

- PhD thesis summary -

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Contents

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Introduction

This PhD thesis addresses a subject of high importance and interest at national and international level, but less known and analysed at national level, namely the NaTech risks.

NaTech risks (*NAtural hazard triggering TECHnological disasters*) are defined by the probability of occurrence of technological disasters triggered by natural disasters (Cruz & Okada, 2008; Ozunu et al., 2011).

The PhD thesis addresses in an integrated manner the NaTech risks generated by land instability in an important area of the energy sector, considered to have strategic importance, namely the natural gas transmission through main pipelines.

Transmission pipelines are considered as one of the most practical, economical and efficient ways of transmission of hazardous and flammable substances such as natural gas, (Brito & Almeida, 2009). Cracking and/or severing of such pipelines as a result of landslide impact leads to the release of natural gas which could cause fires and explosions endangering the safety of people, of goods and the environment.

Concerning the natural risk which triggers the NaTech accident which is studied in this PhD thesis, we refer to landslides. It is important to mention that landslides occur all over the world and have an important negative impact, causing significant property damage, injuries and deaths annually (Yesilnacar & Topal, 2005). Nevertheless, compared to other natural disasters, the landslides can be foreseen, as before their initiation they are preceded by an increase of the stress in the body of potentially sliding land, and the evolution of the stress status can thus be assessed and observed (Goţiu & Surdeanu, 2007).

The selection of the topic is due to the novelty and relevance of addressing and adequately managing the NaTech risks. Such risks are usually studied separately, but the result of their occurrence could materialize into a disaster which cumulates the impact of the natural and technological hazard. Moreover, the urgency of implementing more accurate and effective specific legal measures related to NaTech risks derive from the increased frequency and seriousness of the natural disasters during the past years due to climate change, environmental damage and population growth.

Scope and objectives of the thesis

The scope of the PhD thesis is the development and implementation of a methodology for NaTech risk analysis related to landslides in the area of natural gas transmission through buried main pipelines.

This methodology emphasizes the need for NaTech risk analysis in the preparatory, design and operational phases of the national energy system or other critical national/European infrastructures. Thus, this approach fulfils the following conditions:

- Higher operation security and safety for „important territorial infrastructure objectives of our national defence system" (in compliance with Law no. 477/2003 „on preparation for defence of the national economy and of the territory");
- Eliminating technological, security and financial risks generated by the occurrence of such types of hazards;
- Provides the conditions for alignment to the sustainable development concept.

The objectives set for the fulfilment of the scope of this PhD thesis are the following:

- Presenting a literature study on the impact of landslides on the buried pipelines and current methodologies of assessment;
- Choosing a study area and identification of buried main gas transmission pipelines affected by landslides;
- Analysis of the previous and current situations;
- Elaboration of a landslide hazard and risk maps for the area under evaluation;
- Identification of possible technological hazards and calculation of risk indexes;
- Identification and elaboration of NaTech accident scenarios;
- Analysis of the results and elaboration of conclusions.

Thesis structure

For the achievement of the scope and objectives mentioned above, the PhD thesis was divided into seven chapters as follows:

Chapter 1 includes a general overview of the theoretical concepts on hazard, risk and vulnerability, emphasizing the required information for elaboration of the thesis, such as: definition of terms, hazard classification, etc. This chapter includes theoretical concepts on landslides, as an important part of this study.

Chapter 2 addresses in more detail the natural and technological risks emphasizing their evolution along the years in order to substantiate the importance of NaTech risk analyses. For this scope the chapter includes a more thorough literature study on NaTech risks (characteristics, events that occurred, existing methodologies, etc.).

Chapter 3 presents the theoretical aspects on natural gas and its flow from production to consumer delivery.

Chapter 4 comprises a vast literature study on NaTech risk associated to buried main natural gas transmission pipelines in the context of land instability phenomena. This chapter presents the potential impact of various types of landslides on buried pipelines and the national and international evaluations of such a type of risk. After presenting the existing methodologies in this field, the last subchapter presents the main stages of the developed methodology used in the PhD thesis, which is detailed in the case studies.

Chapter 5 presents the four case studies from the three locations analysed in the PhD thesis, both from the literature study perspective (analyses of the natural setting – terrain, geology, seismicity, climate, etc.) and from the past and current on-site analyses.

Chapter 6 comprises the actual NaTech analysis for all the four case studies. This chapter details the methodology used for NaTech risk analyses. The obtained results are also presented and analysed.

The last chapter, chapter 7, presents the final conclusions of the PhD thesis, the personal contribution and the future perspectives.

The type of analysis proposed in this work is appropriate for areas that are prone to landslides where important industrial infrastructures are located or significant operational risks are involved. The scope of this analysis is to take adequate preventive measures with the view of reducing significantly the possibility of occurrence of a NaTech accident.

1. Theoretical considerations

The hazard is a “dangerous phenomenon, substance, human activity or condition that might generate live losses, harming or health impact, losses of property, losses of living means and services, social and economic disruptions or damages to environment.” (ISDR, 2009).

Another term that is closely related to hazard is the *risk* (Smith & Petley, 2009; Kovacs et al., 2017). The latter represents a potential hazard to which the population and environment are exposed to, representing the action of a hazard or group of hazards which

could have dangerous consequences within a certain time, interval and place (Siwar & Islam, 2012).

$$\mathbf{R = F \times C}$$

R (Risk); F (Frequency); C (Consequences)

Another formula of risk proposes to include vulnerability in the calculation formula, namely:

$$\mathbf{R = F \times C \times V}$$

R (Risk); F (Frequency); C (Consequences); V (Vulnerability)

Vulnerability is the degree of susceptibility of the environment/population/property to be affected by a disaster (Ozunu & Anghel, 2007, Kollarits et al., 2010, Török et al., 2011). It depends on the rate of losses (human casualties and property losses) following the exposure to hazard and it depends on the capacity of a system to react when it is exposed to hazard (Ozunu & Anghel, 2007).

Landslides are widespread and have significant negative impact, causing huge property losses and thousands of human life losses and injuries annually (Yesilnacar & Topal, 2005). They are represented by natural displacements of land mass from the terrain slopes due to fast or slow gravity processes modelling the slopes of the terrain, following the disruption of equilibrium between the gravitational force and the shear force. This is caused by triggering factors of natural or anthropogenic origins (Pardeshi et al., 2013, Kovacs et al., 2015a, Massey et al., 2018, Reichenbach et al., 2018).

As compared to other natural risks generating disasters (like for instance earthquakes or flooding), the landslides can be foreseen, as the triggering is preceded by an increase of stress in the potential sliding land mass, and the evolution of stress can be assessed and observed (Goţiu & Surdeanu, 2007).

2. Natural, technological and NaTech disasters

Natural disasters are geological or meteorological phenomena, with sudden or slow onset (for example, draughts), that lead to major imbalances in the environment and society, sometimes huge efforts being required to cope with them (Young et al., 2004, Kovacs et al., 2015a). The frequency and magnitude of severe natural events are continuously increasing, which is a reason to worry about the possible interference of industrial activities (EEA, 2010;

Kovacs et al., 2018). According to CRED EM-DAT (2018) data base an increase of natural disasters frequency has been recorded starting with 1948 until today.

Technological risks derive from voluntary or involuntary human activities, which can interfere in the functionality of infrastructure within the limits of normal to hazardous, and up to disaster. This type of disaster may have major negative consequences on human health and safety, as well as on property or other patrimony values (Ozunu & Anghel, 2007). Moreover, the technological disasters may have a major negative impact on industrial locations, which contain hazardous materials, oil and gas pipelines and safety systems which can create serious adverse effects for the population and environment (Galderisi et al., 2008). According to CRED EM-DAT (2018) data base an increase of technical disasters frequency has been recorded during the last 40 years, following the increased diversity of technologies and used substances, as well as due to the human errors which can occur during the operating processes (Ozunu et al., 2011). Due to efficient legislative measures for reducing the consequences of technological disaster, their number decrease after 2005.

NaTech risks consist in the probability of occurrence of technical disasters caused by natural calamities (*NAtural hazard triggering TECHnological disasters*) (Cruz & Okada, 2008; Ozunu et al., 2011). Thus, a NaTech accident may occur in a territory if the following two conditions are met, namely:

- The area in question is prone to occurrence of natural disasters;
- There are large quantities of hazardous substances on the territory in question which might produce damages to the existing population (Cruz & Okada, 2008).

Taking into account the history of NaTech accidents, the major impact they have and the increased frequency of occurrence, the scientists are trying to predict and analyse such type of disasters. Thus, many authors have developed various methodologies of assessment of NaTech risks.

Nevertheless, currently there is no consolidated methodology available for the assessment and mapping the NaTech risks in the EU. However, the available the NaTech risks assessment methodologies are practically simple overlapping natural hazards and technological risks without taking into consideration the specific characteristics of the sites or the hazards interactions (Krausmann & Baranzini, 2012). Moreover, at European as well as at national level, it has not been issued any law related to assessment of NaTech risks and their reduction. There are numerous legal rules describing in detail the natural and technological risks, but only separately (Galderisi et al., 2008).

3. Natural gas and its flow from extraction to consumer delivery

Natural gas is located in porous and permeable rocks (sands, sandy marls) and the extraction from the reservoir is made by drilling.

The transportation of natural gas from production areas to consumption areas requires an elaborated system, consisting of a complicated system of pipelines, which transports the gas from the production location to an area with high gas demand.

As related to the underground gas storages, they are particularly important because they provide natural gas supply during the periods of very high demand. Moreover, they secure the gas supply in case of disruption of the domestic gas production (Chisăliță, 2001; Ignat, 2016).

4. NaTech risk associated to natural gas transmission pipelines in areas prone to land instability

If land instability phenomena occur in the area with main gas pipelines, they can cause cracking or severing of the transmission pipelines. The gas released following such severing of the gas transmission pipelines can cause fires and explosions, which might lead to loss of lives, major economic losses and environmental damages.

The NaTech accidents related to buried pipelines in landslides prone areas have been frequent in the past years (Zheng et al., 2012). Taking into consideration the accidents that have already occurred at gas transmission pipelines due to land sliding and their consequences, the authorities became increasingly aware of the importance of assessing the NaTech risk (Han & Weng, 2011).

5. Case study: NaTech events occurring at main gas transmission pipelines affected by landslides

The case studies have been selected based on the landslides sensitivity map and of the gas transmission pipeline routes in Romania, namely the main gas transmission pipelines affected by landslides from the North-West part of Romania.

This chapter presents the case studies, along with previous and current on-site analyses.

6. NaTech risk analysis for natural gas transmission pipelines affected by landslides

For the presentation and application of NaTech risk analysis methodology, four case studies from the area presented in the previous chapter have been considered. It is worth mentioning that this methodology can be applied for the current main gas transmission pipelines routes from the design phase, but also for assessing the risks in the existing locations.

The first stage of the NaTech risk analysis consists in the elaboration of the hazard maps and of the landslide risk maps for the three areas. Later on, in order to calculate the NaTech risk, the technological accidents scenarios were identified, the probability of yielding was assessed and the risk indexes for all the four case studies were calculated. The NaTech risk maps for all the four case studies were developed using this methodology (Fig. 1. – Fig. 4).

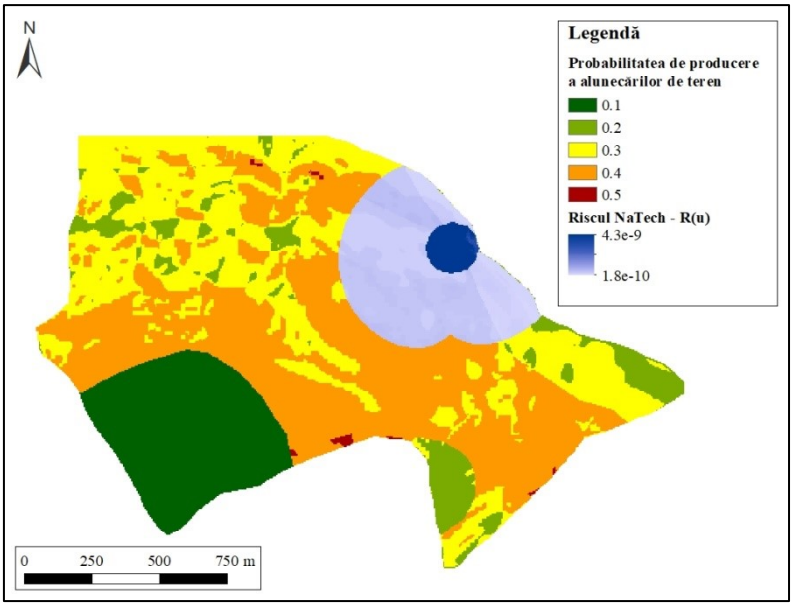

Fig. 1. NaTech risk. Teceu Mic area

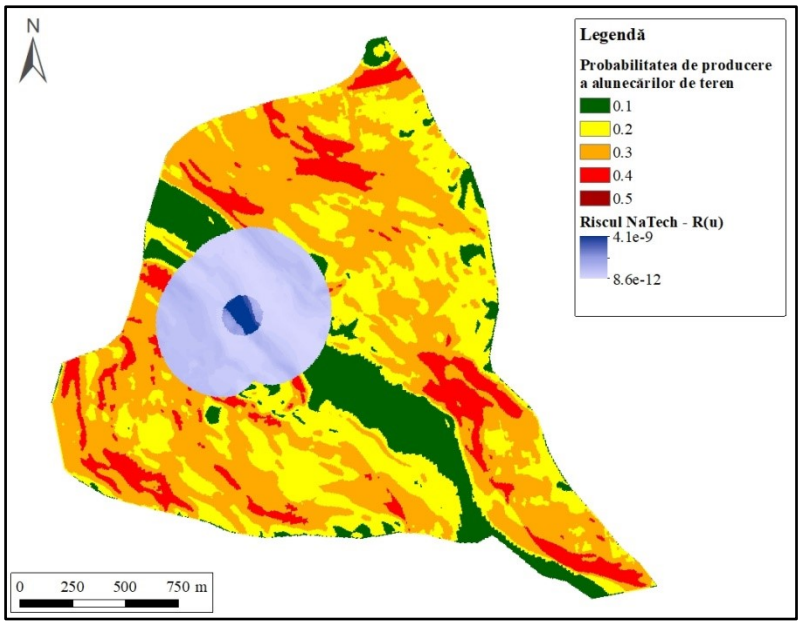

Fig. 2. NaTech risk. Vâlcele area

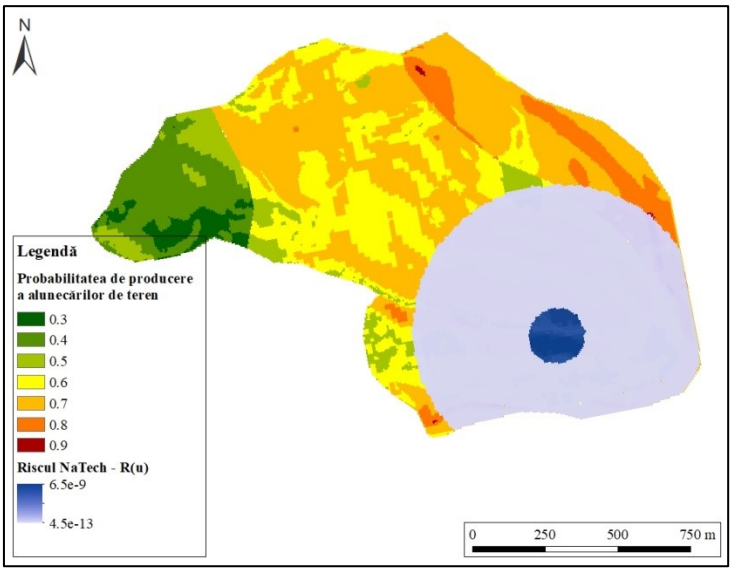

Fig. 3. NaTech risk. Sucutard I area

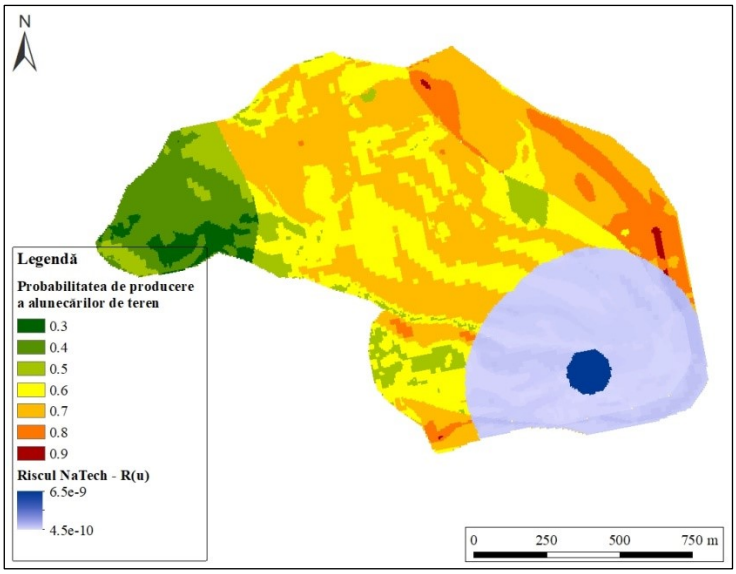

Fig. 4. NaTech risk. Sucutard II area

The threshold value for NaTech risk assessment was considered the threshold value of the individual risk from the specific literature. Thus, it is considered that any frequency lower than $1*10^{-6}$ corresponds to an acceptable risk level, while values exceeding $1*10^{-5}$ are considered unacceptable (Cornwell & Meyer, 1997, Trbojevic, 2005, Duijm, 2009). Although the NaTech risk could have been considered acceptable, such events occurred and the population would have been affected if at least one person had been present at the place of the accident and if no intervention in due time on the buried gas transmission pipelines had been made to stop the gas flowing in the atmosphere because of pipeline severing. If such analysis had been made before the lay down of the main gas transmission pipeline in the respective area or after the first occurrence of landslides, such accidents would have been avoided and implicitly the direct and indirect property damages supported by the economic operator would have been reduced. It is important to develop such studies for the benefit of human, environment and economic safety, and even more for industrial sites, which are near residential areas.

The highest annual rate of direct property damages caused by landslides is in residential areas. Nevertheless, when a NaTech accident occurs, the total property damages supported by the economic operator for gas transmission are much higher than the estimations calculated for a single natural risk. Industries have to support both direct property damage: the replacement of the section of severed pipeline, as well as the indirect ones: payment of land lease during the execution of the pipeline replacement works, payment of

third parties compensations for disruption of gas supply, payment of required equipment and man work, the damage to the image and reputation of the company etc.

It is important to develop NaTech risk analysis in landslides prone areas where industrial objectives are located, which should consider both the natural hazard and its impact and the technological risk and its consequences, as well as the cumulated impact of these two types of disasters. The performance of such studies is particularly important from the human safety and economic perspective.

7. Conclusions, personal contributions and future perspectives

This work considered four case studies from three different geographical areas, areas where main buried gas transmission pipeline were affected following the impact of landslides. Thus, the methodology elaborated and implemented within this PhD thesis consists of an on-site analysis of the current situation and the analysis using dedicated software for assessing landslides and technological risk, as well as NaTech risk. Thus, this work proposes an original approach of NaTech risk analysis for the gas transmission industrial sector.

The personal contributions in this work are the following:

- Study of literature on the impact of landslides on main gas transmission pipelines;
- Study of literature and creation of a database of completed studies and currently existing methodologies on NaTech risk for main gas transmission pipelines located in landslides prone areas;
- Case studies performed in important areas of the energy sector, considered to be of strategic importance, namely for main gas transmission pipelines infrastructure;
- Presentation and application of a complex methodology of NaTech risk analysis for gas transmission in landslides prone areas, both related to compliance with the legal requirements on health, environment protection and property damage, and related to providing the national energy security premises;
- Presentation of a methodology that can be equally applicable to important economic objectives or with significant operation risk as well as to economic objectives in project phase;

- Interpretation of results obtained from NaTech risk analysis for the four case studies.

It is worth mentioning that the methodology developed in this PhD thesis could be useful both to economic operators and to authorities for the elaboration of NaTech studies or analysis reports, in order to eliminate or to reduce to an acceptable level the consequences of a possible accident of this kind.

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