SSM
Scuola Superiore Meridionale

MERC PhD Project Proposal

Title of the research project

Multi-hazard risk analysis of industrial facilities considering high-consequence low-probability events

Keywords

NaTech; reliability; black swan; hazard interaction

Supervisors

Iunio Iervolino, iunio.iervolino@unina.it , http://wpage.unina.it/iuniervo/
Structural dynamics, earthquake engineering, risk analysis
Ernesto Salzano, ernesto.salzano@unibo.it, https://www.unibo.it/sitoweb/ernesto.salzano/en
Industrial risk, deflagrative and detonative combustion phenomena, NaTech risk.
Georgios Baltzopoulos, georgios.baltzopoulos@unina.it, http://wpage.unina.it/georgios.baltzopoulos/
Structural engineering, seismic vulnerability of infrastructure, bridge engineering

Project description

One of the challenges in quantitative risk analysis of industrial facilities, is accounting for multiple hazards in risk computations, as well as accounting for, so-called, *high-consequence low-probability* (HCLP) events. HCLP events, sometimes referred to under the literary metaphor of *black swans*, can be defined in the context of industrial risk analysis as events causing the unlikely simultaneous failure of multiple safeguard mechanisms, leading to industrial accidents (e.g., releases of hazardous materials at industrial installations housing chemical processes) with catastrophic consequences. Such accidents, that can be triggered by natural hazards such as earthquakes and tsunamis or hurricanes, are often referred to as NaTech events.

A notorious example of such a HCLP NaTech event is the Fukushima Daiichi nuclear disaster, which occurred in the wake of the 2011 Tohoku earthquake in Japan. In that case, the combination of ground shaking and subsequent inundation by a tsunami wave, led to the failure of enough back-up safety systems to provoke a major nuclear accident. In fact, hindsight indicates that many past HCLP events, including the Fukushima Daiichi incident used as an example, are consequences of unforeseen interactions between multiple hazards, natural or anthropic, to which a system is exposed.

In this context, the research objectives of this project can be summarized as follows:

Quantification of the interaction of natural (hurricanes, floods, earthquakes) and anthropic (sabotage, terrorist attacks, operator errors) perils at the hazard level; probabilistic quantification of the joint occurrence of one or more triggering events is an important open issue in multi-hazard risk analysis. This is especially true in the case where some of these hazards are not independent, for example in the case of earthquakes and tsunami.

Quantification of multi-hazard interaction at the system level; the occurrence of two or more hazardous events within close temporal proximity can lead to the first-arriving event increasing the system's vulnerability to the second, thus exacerbating the overall impact. One example can be damage accumulation in key components/facilities of an industrial complex due to a seismic event, which can increase the probability of an accident before remedial measures can be taken to mitigate the increased risk.

- Incorporation of high-consequence low-probability scenarios within the industrial quantitative risk analysis framework; the a-priori identification of HCLP scenarios within a complex system is a challenge in itself, due to the interdisciplinary nature of studying multi-hazard triggering events. Another challenge is incorporating the potential consequences of such events in quantitative risk analysis, due to the inherent difficulty in estimating occurrence rates for low-probability events.

The methodology expected to be followed when tackling these challenges, is divided between innovative approaches to hazard, vulnerability and identification of multi-hazard triggering scenarios. On the hazard front, an extension of traditional probabilistic hazard analysis will account for the joint occurrence rate of natural phenomena with specific intensities and their interaction with anthropic perils. On the vulnerability front, the definition of state- or damage-dependent fragility functions for industrial component or facilities will be pursued. This will have to be combined with a probabilistic treatment of HCLP event scenarios inducing damage states that traditional parametric fragility functions cannot capture by definition.

Relevance to the MERC PhD Program

Multi-hazard quantitative risk analysis of industrial facilities is, by its very nature, a multi-disciplinary task, being traditionally separated into a study of hazards potentially impacting the facility, infrastructure vulnerability and the study of cascading effects of component/facility failures and their consequences. Quantification of natural hazards potentially impacting the industrial site may require expertise in a variety of disciplines, such as engineering seismology, wind engineering, flood and coastal engineering, to name a few. Estimating component and facility vulnerabilities to these hazards typically requires the collaboration of structural and industrial engineers. Finally, quantification of the adverse consequences of natural-hazard-induced failures, in the form of cascading effects such as fires and explosions leading to the release of dangerous substances, requires expertise in chemical engineering.

The rational estimation of the risk to which large industrial complexes are exposed, is a topic that has been attracting the attention of major stakeholders, such as re-insurance companies, over the past decade. Bringing multi-risk analysis up to the standard of single-natural-hazard risk analysis, e.g., seismic risk, and accounting for high-consequence events is the next frontier in this field.

Key references

Paté-Cornell, M.E. (1994). "Quantitative safety goals for risk management of industrial facilities". Structural Safety, 13, 145-157.

Fabbrocino G., Iervolino I., Orlando F., Salzano E. (2005). "Quantitative risk analysis of oil storage facilities in seismic areas". Journal of Hazardous Materials, 123(1-3):61-69.

Krausmann E., Cozzani V., Salzano E., Renni E. (2011) "Industrial accidents triggered by natural hazards: an emerging risk issue". Nat. Hazard Earth Sys., 11, 921–929.

Mignan A., Wiemar S., Giardini D. (2014). "The quantification of low-probability–high-consequences events: part I. A generic multi-risk approach". Natural Hazards, 73, 1999–2022.

Iervolino I., Giorgio M., Chioccarelli E. (2016) "Markovian modeling of seismic damage accumulation". Earthquake Engineering and Structural Dynamics. 45(3):441–461.

Joint supervision arrangements

Weekly meetings with the first supervisor. Monthly meetings with both supervisors.

Location and length of the study period abroad (min 12 months)

Dimitrios Vamvatsikos divamva@ntua.gr
Associate professor
National Technical University of Athens

Any other useful information

-