PhD proposal: Fragility assessment of damaged structures under dynamic loading using stochastic models

Keywords:
Numerical modelling, fragility analysis, risks, decision making

Societal and scientific context:

In the context of global change, natural phenomena are becoming increasingly threatening for people, infrastructures, and entire territories. This is especially true in mountainous areas, particularly exposed to rapid, sudden, and violent events such as rockfalls, torrential floods, snow avalanches, and landslides. The risk level for the exposed assets depends on the phenomena's nature, intensity and occurrence probability, but also on the physical vulnerability of each exposed element. In this context, managers of critical infrastructures and territories need a better knowledge of the level of risk, uncertainties, and improved risk-informed decision methods.

This PhD project aims to address this need by characterizing the physical impacts of various phenomena on the assets at risk. It is part of a broader project PRISM (Predictive Risk-Informed asset Strategic Management), funded by the MIAI Cluster IA of University Grenoble Alpes. The PRISM project seeks to develop decision-support methods for the dynamic management of vulnerable assets under uncertainty and in the presence of heterogeneous information sources. The methods developed will integrate different forms of knowledge (physical models, sensor data, control system data, expert judgment…) into a unified stochastic framework. This surrogate model will then be used to design predictive decision-making strategies. The specific focus of this PhD is on the development of methodologies for constructing fragility curves for exposed infrastructures such as bridges, or protecting works. A partnership is planned with the local authority in charge of infrastructure maintenance in the Isère department, providing access to existing data. These data will be analyzed to calibrate and validate the proposed models.

Roadway destroyed due to flooding, Saint-Christophe-en-Oisans. Credits: Jean-Louis Arthaud / Mairie de Saint-Christophe-en-Oisans. Source : www.francebleu.fr

Scouring phenomenon downstream a check dam. Saint Antoine torrent, France, 2014. Source: ˝ INRAE/ETNA. [Chahrour et al., 2021]

Scientific project:

The assessment of the structural performance of assets at risks faces several challenges. The first challenge lies in the heterogeneous and incomplete information on the structural state (uncertainties related to geometry and material characteristics, as well as to the ageing state of the structure), and on the loading, coming from the uncertain event. To address this issue, fragility curves are a useful tool. The purpose of the fragility analysis is to give the failure probability of the considered asset, given a level of hazard. Fragility analysis has been widely developed in the context of the seismic risk assessment. The interested reader can for instance refer to [Zentner, 20217] for the global fragility analysis methodology in the context of seismic risk assessment, or to [Pitilakis, 2014] for fragility analysis methodologies applied to masonry building. Although fragility curves are also relevant to address the risk due natural hazard ([Eckert, 2012]), there is still a lack of development of fragility analysis for gravity-driven natural hazards ([Favier, 2018]). The PhD project aims at bridging this gap by developing fragility relationships for assets at risks using numerical simulation.

To take into account all the uncertainties, the computation of fragility curves intrinsically implies numerous case-studies. Thus, suitable modelling strategies are needed to keep the computational cost reasonably low. Stochastic finite element approaches can be used to quantify and propagate uncertainties [Stefanou, 2009]. These approaches need to be coupled to models able to compute the physical response of the asset at risk. The development of such physical models, simple enough to keep the computational demand low, but precise enough to represent the key features of the structural behavior, is still a topical scientific issue. For instance, [Stocchi et al, 2021] propose an efficient global methodology to address the nonlinear behavior of existing masonry structures under moderate seismicity. The modelling strategy is based on the identification of equivalent nonlinear single degree of freedom oscillators, for which the computation of the response is almost instantaneous. [Favier, 2018] propose a similar physical model for the fragility analysis of a reinforced concrete wall subject to snow avalanches. The present project aims at answering the question of the choice of the most suitable tools to include the available data into a stochastic model, coupled to a physical model at the structural scale. Models of increasing complexity will be developed.

Indeed, the second challenge of the structural performance assessment lies in the different levels of degradations that can be caused by the natural event. If superficial disorders can be easily represented by existing simplified modelling strategies, severe cracks can also occur, inducing a high non-linearity in the material behavior. Representing the effect of this local damage at the structural scale is still a challenging question in the computational mechanics scientific community. The present proposal seeks to address this issue by developing multi-scale modeling strategies, such as fiber beam elements with strain enhancement accounting for damage [Capdevielle, 2021], or coupled to homogenization strategies [Ariza, 2021, Franco, 2022].

With the above-mentioned scientific developments, this PhD project aims at improving the asset condition prediction using the available heterogenous data. A better knowledge of the asset response to the natural hazard will also help determining the degradation thresholds, which are used to assess risk level but also to choose and evaluate maintenance strategies.

Location: 3SR Laboratory

The 3SR-Lab is a joint research unit of Université Grenoble Alpes, Institut Polytechnique de Grenoble and CNRS, which brings together researchers in soil, solid and structural mechanics. It conducts cutting-edge research in the fields of structural, structures and materials engineering, for applications in the civil engineering, energy, transportation and health sectors, as well as in the industry. To do so, its researchers implement a multiscale methodology combining experimental mechanics (tests on materials, imaging techniques, testing at the scale of structures), theoretical mechanics (behavioral laws, enriched continuous media) and numerical mechanics (simulation of structures by finite elements or volumes, discrete elements)

Supervision and contacts:

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Desired profile:
The ideal candidate will have strong skills in mechanics and numerical methods, as well as a keen interest in theoretical work and programming. Prior experience in coding (for example with softwares like Matlab or Python) will be highly valued. The PhD proposal combines applied mathematics approaches to Civil Engineering applications, thus an interest for both is essential to succeed in this work. Personal qualities such as curiosity, scientific rigor, perseverance, and autonomy will be key assets for successfully completing this project.

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