ERIES: ADVANCING FRONTIER KNOWLEDGE IN EARTHQUAKE ENGINEERING THROUGH LABORATORY TESTING

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Abstract: *This paper provides an overview of European research synergies towards loss and risk-driven mitigation approaches, focusing on the EU-funded ERIES (European Research Infrastructures for European Synergies, www.eries.eu) project. ERIES aims to provide transnational access to advanced experimental facilities in Europe and Canada, supporting the advancement of knowledge in structural, seismic, wind, and geotechnical engineering. The project's structure is described, along with its broader research goals and themes addressed. A case-study example project currently underway at the Eucentre Foundation in Pavia, Italy is highlighted to illustrate the kind of research possibilities available within ERIES. It shows how the fundamental research that is possible using this funding mechanism can have notable impacts on the characterisation of damage accumulation in structures, shedding much-needed light on issues like mainshock-aftershock sequences in seismic risk assessment but also the calibration of experimental loading protocols used in laboratory testing. To sum up, the ERIES project is a driving force for research collaboration in Europe, specifically in the areas of structural, seismic, wind, and geotechnical engineering. Its framework and transnational access projects allow for impactful research to be conducted, leading to better understanding of damage in structures and informing risk assessment methods, benefiting society as a whole.*

1 Introduction

Natural disasters continue to cause immense harm worldwide, directly and indirectly, damaging buildings, and affecting the economy and society. In particular, earthquakes and strong winds are responsible for direct destruction, financial losses, and interruptions in essential services. Investigations into the impact of soil-structure interaction and geotechnical disasters such as liquefaction, have still not been completely addressed, and more innovative research and developments are needed to fully understand the combined effects of these hazards.

Recent seismic events, ranging from L'Aquila in 2009, to Central Italy in 2016-2017, Samos Island in the Aegean Sea in 2020, Albania in 2019, and Croatia in 2020, have had huge impacts on societies. The 2020 earthquake in the Aegean Sea, for example, caused an estimated 400 million Euros in financial loss and made homeless around 15,000 people. In Albania during November 2019, the earthquake took 52 lives, injured 3,000 people, made 14,000 homeless, and ruined over 14,000 buildings. In Croatia, the Petrinja earthquake also caused extensive damage and made reconstructive efforts more complex and costly due to geotechnical instabilities, soil liquefaction, and the manifestation of sinkholes. Similarly, extreme weather events related to climate change can potentially cause severe losses to structures and infrastructure. In the 1980s, the Great Storm of October 15th, 1987 brought about €5M in damages and 34 fatalities in France and the United Kingdom. Similarly, the Lothar and Martin storms in December 1999, caused €13.5M in damages and killed 125 people in Europe. The increasing frequency of such events due to global warming has drastically increased economic losses. Records from the European Severe Storm Laboratory show that in the last 3 years, 60,000 cases of structural damages and collapses have been attributed to extreme winds across Europe, highlighting the immense economic damage, distress, and risk to lives associated with thunderstorms and tornadoes. In the future, these storms are only likely to become more destructive due to the effects of climate change. Munich Re (2014) reports that economic losses caused by natural disasters are generally divided equally between earthquakes (35%), floods (30%), and wind storms (28%). In terms of death tolls, earthquakes (47%) and wind storms (45%) far surpass floods (7%).

The effects of these events are evident, highlighting the necessity for further innovative research and technological advancements. This will enhance the resilience of new and existing structures and infrastructures. For example, further examination is needed on the seismic performance of non-structural elements since they are a known cause of economic losses, pose a life-safety hazard for occupants, and may result in downtime. This can be done through the experimental testing and evaluation of different components, along with developing innovative solutions that can mitigate their impacts. Furthermore, the integration of risk-based concepts used in risk management and insurance sectors into a more engineer-based context like the design, assessment and practical implementation of structural solutions still has large gaps that need to be addressed.

Figure 1. Locations of ERIES research infrastructures

2 ERIES Project

The ERIES project (European Research Infrastructures for European Synergies, www.eries.eu) responds to the European Commission's Horizon Europe call INFRA-2021-SERV-01-07: Research infrastructure services advancing frontier knowledge with the overall objective of providing transnational access (TA) to advanced research infrastructures in the fields of structural, seismic, wind and geotechnical engineering. This project, together with the research infrastructure team assembled, provides access to leading experimental facilities that permit users to advance frontier knowledge and conduct curiosity-driven research towards: the reduction of losses and disruption due to these hazards; the management of their associated risk; and the development of innovative solutions to address them that will contribute to a greener and more sustainable society. To this end, ERIES offers TA to the best European experimental facilities in each field, with new and unique infrastructures available for the first time in this programme, along with the provision of key infrastructure in Canada, illustrated in Figure 1. ERIES seeks to set future standards in experimental techniques for earthquake, wind and geotechnical engineering. Moreover, it provides a platform for researchers to generate creative solutions and evaluate potential applications of advanced technologies. The programme is spearheaded by 13 partners from 8 countries, with the aim of minimizing losses, managing risks, and creating a more sustainable engineering future for Europe.

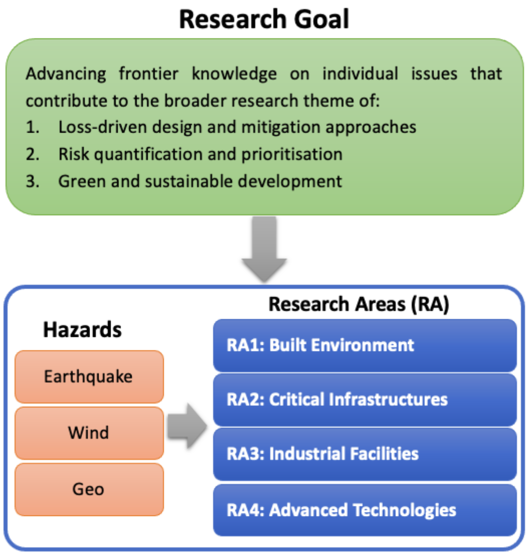

Figure 2. Illustration of research goals along with the four research areas and hazards to be addressed

2.1 Research Areas and Goals

To do this, ERIES identifies three specific research goals and research areas within which to focus its experimental activities, shown in Figure 2. These have been broken down into specific areas that can be studied for all hazards and will be specifically mentioned in the calls for proposals made for the TA user groups. In particular, they relate to:

Research Area 1 (RA1): Built Environment **-** This encompasses the structures in which we live and occupy each day. They are analysed from a single-structure perspective in relation to their associated attributes; these cover the building typology (e.g., reinforced concrete, steel, unreinforced masonry), the occupancy type (e.g., residential, commercial, office) and other pertinent issues like the non-structural elements and building contents.

Research Area 2 (RA2): Critical Infrastructures - This encompasses the structures which form a more strategic and regional part of daily life. They are analysed singularly but with a view to encompassing their cascading effects on the networks to which they belong. Road, rail, water, gas or electric networks and other infrastructures like wind turbines and power plants are the main focus, which can then be subdivided based on more detailed attributes like typology (e.g., bridge, transmission line, concrete, steel), structural system (e.g., simply supported, arched, precast) in addition to the study of geotechnical issues and supplemental device behaviour (see also RA4).

Research Area 3 (RA3): Industrial Facilities - This encompasses the structures which form the basis of much industrial activity and whose characteristics and needs do not necessarily fall under RA1. In particular, industrial facilities like factories and production plants, which play a crucial role in the economic functionality of a region, are dealt with in a more specific manner. Issues like the structural performance of the unique structures that house such industrial production will be examined, in addition to the non-structural elements (see also RA1) and other components that typically occupy these facilities.

Research Area 4 (RA4): Advanced Technologies - Differing from the previous three RAs, this research area focuses on the advancement of technologies. This is done first from a mitigation devices perspective, whereby existing technologies such as base isolation, viscous dampers and other innovative green and sustainable materials are developed and can be readily implemented in practice. It is envisioned that their development can also produce an indirect impact on RAs 1-3 previously described. Secondly, this research area focuses on experimental techniques as a topic to be further developed. That is, the capacity of the different RIs to develop and expand their capabilities, with a focus on the different partners' laboratories working together in a novel form of hybrid testing, will be given adequate consideration.

2.2 Research Goals

For each of the research areas outlined and hazards studied, TA projects conducted as part of ERIES will all address the fundamental research goals, also shown in **Error! Reference source not found.**. In particular, they relate to:

Research Goal 1: Loss-driven design and mitigation approaches

The fact that there are still important "open" issues in the design and retrofit of structures against natural hazards is clear and their potential impact in terms of economic losses, casualties and overall disruption (i.e., indirect loss) has been repeatedly highlighted in past events. This first research goal focuses on loss-driven mitigation approaches.

In the case of seismic design, current approach possesses a number of flaws both on a technical and conceptual level. It is clear that even today when structural behaviour is understood with a degree of confidence in many cases, it is still not abundantly clear what their target performance should be and how it should be ensured. This applies to structures forming a part of the built environment (e.g., residential buildings), critical infrastructures (e.g., bridge network) and industrial facilities (e.g., processing plants) which form part of RAs 1-3 of ERIES. ERIES will work through its TA activities to address both of these issues. This will be primarily through the development of necessary data for loss-based approaches.

Design optimisation to prevent disruptions and minimise economic losses under wind actions is another one of the major goals for ERIES project. From the damage surveys after increasingly frequent disruptive events, main impacts are observed for residential and commercial/office high-rise and low-rise buildings embedded in complex historical urban environments (RA1), especially due to non-structural components damages; for slender and flexible structures, such as bridges, poles, towers and transmission lines (RA1, RA2, RA3); for critical infrastructures as ports and airports where a large number of strategic activities are daily deployed (RA2); as well as for light and heavy industries (e.g., factories and production plants) (RA3). In addition to that, the designing of new facilities/equipment/tools inspired by the well-settled worldwide facilities commonly used to accurately reproduce and simulate natural disasters, is of crucial importance (RA4). The exceptional network of advanced research facilities will boost the advancement in the knowledge of wind effects on structures, structural and non-structural elements. Damage mechanisms, potential repair actions and associated costs will all be targeted via numerous testing campaigns, in order to foster the development of a database of damage and cost functions for loss-driven assessment and design that will form a next-generation approach of reducing wind risk.

With reference to geotechnical applications, soil-structure interaction (SSI) effects are typically neglected in design of new structures and assessment of existing ones, on the perception that this invariably leads to broader safety margins. This traditional approach has significant implications in the evaluation of losses because the seismic demand may be overestimated and the real structural behaviour could be different from that expected.

Research Goal 2: Risk quantification and prioritisation

While the first research goal focuses on the loss-driven application of research, the second research goal focuses instead on the risk-related aspects. This involves risk quantification, management and prioritisation as part of a more general thrust towards increased resilience and robustness of society to natural hazards. As such, TA activities carried out toward this goal should be geared in a way that they are making a clear contribution toward this increase in resilience and robustness.

For what concerns seismic risk, the increased understanding of structural dynamics and response to earthquake loading in the 1970s and 1980s (Housner, 1984) resulted in the introduction of probabilistic approaches in earthquake engineering. It was initially embraced by building codes like Eurocode 8 but in an indirect way although the recent draft revision to Eurocode 8 includes a much more detailed annex describing this probabilistic approach. To facilitate the implementation of this in the European context, much data is still needed to verify and calibrate for certain contexts these mathematical models that form the basis of probabilistic seismic risk analysis.

The operational management of large wind sensitive infrastructures, including alert systems, is often ruled by wind, influencing the safety of people but also the economic performance and cost efficiency of the infrastructure (e.g., Repetto et al., 2018). ERIES provides extensive experimental infrastructure and technical knowledge to aid research for potential users across various application fields. This enables precise monitoring and simulation of wind flow characteristics, along with the assessment of structural and infrastructural response and vulnerability at different temporal and spatial scales. The resulting database will facilitate an advanced systemic approach to risk assessment for buildings and infrastructures. This will enhance the preparedness and resilience of urban areas exposed to wind hazards.

When assessing geotechnical risks, it's important to take into account SSI effects. Failure to do so could lead to inaccurate results, with risks being underestimated if SSI is harmful, or overestimated if it's beneficial. Only when SSI effects are negligible can reliable results be obtained.

Research Goal 3: Green and sustainable development

The issue of green and sustainable development is a research objective that permeates each research area and hazard addressed in ERIES. This reflects the collective action needed in order to work towards a more green and sustainable engineering sector. It must also effectively contribute towards the mitigation of the effects of climate change and improve overall energy efficiency of constructions in general.

Recent research in many European countries is focusing on integrated approaches to structural rehabilitation that include discussions about energy and other impacts. For example, not just consider the impacts of earthquakes on structural behaviour, but also how the energy efficiency and environmental impacts of different structural interventions may be considered and optimised. These efforts represent a clear and positive step towards a greener and more sustainable environment. While such studies have outlined frameworks, they fundamentally rely on experimental evidence and data for new green and innovative solutions that can be considered in these processes. Here, ERIES plays a key and crucial role by allowing users to conduct experimental investigations on innovative materials and technologies.

ERIES is dedicated to renewable energy, specifically in the wind and solar energy sectors. TA users can use our services to study and enhance the performance of horizontal- and vertical-axis wind turbines at various scales and arrangements. Additionally, wind tunnel tests can be conducted on photovoltaic panels to optimise their structural design, maximise their efficiency, and minimise the risk of interruptions. Services also include geotechnical applications such as thermal piles and pile groups and the exploration of innovative micro-power plants and smart grid solutions.

3 Summary

This paper provides an overview of European research synergies aimed at developing loss and risk-driven mitigation approaches. The focal point of the discussion is the ERIES ERIES project (European Research Infrastructures for European Synergies, www.eries.eu) project, which is an EU-funded initiative designed to facilitate transnational access to advanced experimental facilities in Europe and Canada. These facilities enable European researchers to advance frontier knowledge in structural, seismic, wind, and geotechnical engineering.The ERIES project establishes a framework encompassing various transnational access projects, ensuring they align with the broader research thrust. This framework includes defined research goals and research areas, which serve as guiding principles for the projects conducted within the initiative.

In conclusion, the ERIES project serves as a catalyst for European research synergies, promoting transnational collaboration and facilitating the advancement of frontier knowledge in the domains of structural, seismic, wind, and geotechnical engineering. Through its framework and transnational access projects, the initiative enables impactful research that contributes to the characterisation of damage in structures and informs risk assessment methodologies, benefiting society as a whole.

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