

TITLE OF THE RESEARCH PROJECT

Rehabilitation and Monitoring of Historic Concrete and Masonry Arch Bridges in Italian and French Heritage (ReMoBridge)

SUPERVISORS

	First name	LAST NAME	University	Research Unit
Supervisor	Fausto	Minelli	Università degli Studi di Brescia	UNIBS (Italy)
Co-Supervisor	Carmelo	Caggegi	Université Savoie Mont Blanc	USMB (France)

Fields of study

Engineering, Architecture

Requirements (academic background, languages...) needed to apply for this research topic

Civil engineering, Architectural engineering, Building Engineering.

5 main KEYWORDS

Arch bridges, Concrete & Masonry, Structural rehabilitation, Monitoring, Retrofitting

ABSTRACT (250 words max.)

Arch bridges are key components of transport infrastructure, valued for their structural sophistication and architectural elegance. Their use in Southern Europe dates back to the Roman era, when masonry construction reached high levels of refinement. At the same time, Roman concrete (opus caementicium), the precursor of modern concrete, enabled the construction of increasingly ambitious vaulted structures, such as the Pantheon dome in Rome. From the late 19th century onward, reinforced concrete gradually replaced masonry in bridge technology (partially not totally), leading to the construction of large span arches still used nowadays for constructing new bridges.

Masonry and concrete arch bridges are widespread across Europe, with Italy and France hosting an extensive heritage. The extensive survey programs promoted by the Italian Government since 2020 revealed the pathologies and the material decay involving a considerable number of existing bridges. Moreover, the steady increase in traffic loads demands continuous safety assessments and targeted retrofitting strategies.

This project aims to advance knowledge of typical arch bridges in Italy and France, with emphasis on both structural and architectural characteristics. Selected case studies will be analyzed through advanced monitoring techniques to identify structural deficiencies and develop innovative retrofitting solutions to

mitigate vulnerabilities. The data provided by the monitoring activity will also enable accurate modeling of structural behavior and prediction of deterioration rates, supporting the estimation of residual service life.

Research aims and methodology

Arch bridges are among the most distinctive and enduring components of transport infrastructure, combining structural aspects with architectural elegance. Across Europe, and particularly in Italy and France, masonry and concrete arch bridges are part of the heritage structures needing assessment and preservation. They embody a rich diversity of construction techniques, materials, and typologies that reflect not only the availability of local resources but also the social, cultural, and technological context of their time. However, these structures are now facing pressing challenges. Recent nationwide surveys in Italy, initiated in 2020, have revealed widespread pathologies and material degradation affecting bridges of different ages and typologies. The continuous growth of traffic demand and vehicle loads, which far exceed the resistance required at the time of construction, further increase the need for systematic assessment. Moreover, the location of many arch bridges in seismically active regions of Southern Europe underscores their vulnerability to seismic events, adding additional risk for both safety and heritage preservation.

In response to these challenges, the present project sets out a multidisciplinary research program aiming at enhancing scientific and technical knowledge on historic arch bridges and developing effective, sustainable strategies for their conservation, monitoring, and rehabilitation. The approach integrates different aspects of architecture, structural engineering and survey strategies, including advanced monitoring techniques.

The first research strand focuses on a historical and typological study of arch systems across different European regions, with special attention to Italy and France. Construction techniques, materials, and structural configurations will be analyzed across time periods, to identify common patterns and regional specificities. This work will be informed by archival research, technical drawings and manuals, when available. On-site investigations will complement this documentary research, enabling the cataloguing and comparison of arch and vaulted systems, leading to the selection of the case studies that will be used in the following part of the research program.

Building on this knowledge base, the second phase of the project addresses the structural assessment of historic arch bridges. Unlike modern structures, which are designed according to codified standards, historic bridges were typically built using empirical rules and practical experience. As a result, they often present static and dynamic vulnerabilities, aggravated by ageing materials and environmental exposure. Advanced monitoring techniques, including non-destructive testing and sensor-based data acquisition, will be used to capture and investigate the structural behaviour. Beside traditional monitoring techniques, the research will investigate the use of Fiber Optic sensors for the strain and deflection assessment of bridges selected as case studies within the research program. The adopted instrumentation will allow to detect settlements and the evolution of crack patterns in order to recognize mechanisms that are potentially detrimental of structure capacity and stability. The data obtained from monitoring will be integrated with refined analytical and numerical models, enabling accurate prediction of deterioration processes and residual service life.

The third strand of research is devoted to retrofitting and rehabilitation strategies. Given the cultural value of heritage arch bridge structures and their role as vital arteries within the framework of our infrastructure, interventions must be both technically effective and respectful of architectural integrity. Retrofitting solutions will therefore be developed according to the principles of sustainability, material compatibility, and reversibility, while also incorporating advanced high-performance materials where appropriate. Technical guidelines will be produced, covering: (1) classification of typical damage patterns in masonry and concrete arches; (2) simplified analytical methods for preliminary design; and (3) intervention strategies tailored to specific cases related to both masonry and concrete bridges. The guidelines will be illustrated through selected case studies, ranging from monumental heritage structures to “minor” functional bridges, providing practitioners with reference models for diagnosis and intervention.

A fourth component of the project is experimental validation. Laboratory tests will be conducted on small- and full-scale specimens, such as masonry arches/vaults and reinforced concrete girders, both before and after retrofitting. These tests will simulate static and seismic actions to assess the actual effectiveness of proposed interventions. The experimental campaign will include also material tests, which are fundamental to characterize the mechanical behaviour of advanced materials used in the retrofitting interventions. The experimental tests on large scale specimens will be mainly carried out in the structural engineering laboratory “P. Pisa” at the UNIBS, whereas the material tests will be performed mainly in the laboratory of USMB. The results will not only validate numerical and analytical models but also contribute to the refinement of retrofitting methodologies and design recommendations.

Beyond its scientific and technical contributions, the project has broader social implications. By safeguarding existing bridges, it contributes to the preservation of cultural identity and architectural heritage. By improving safety and serviceability, it ensures the continued functionality of essential transport infrastructure. Moreover, by fostering collaboration across the different universities and disciplines involved in the research program, it strengthens the network of researchers and professionals engaged in heritage conservation.

Relevance and added-value of the proposed research in relation to the current state of knowledge

The structural behaviour of bridges has been extensively investigated in recent years, largely in response to a number of high-profile collapses that have occurred worldwide. These tragic events have highlighted both the vulnerability of ageing infrastructure and the urgent need for systematic approaches to their monitoring and maintenance. Numerous studies have demonstrated the importance of continuous structural monitoring as a means of assessing safety, predicting potential failure mechanisms, and informing maintenance strategies. In this context, the development and implementation of new monitoring techniques, together with the validation of innovative retrofitting methodologies, emerge as priorities for ensuring the long-term functionality and resilience of bridge infrastructure.

While much research has been devoted to contemporary bridges or to general aspects of bridge health monitoring, the present project addresses a distinct yet highly relevant category: historic masonry and concrete arch bridges. These structures are not only vital components of transport networks but also represent an invaluable cultural and architectural heritage that demands careful preservation. Unlike

other studies, this research aims to provide a significant and practice-oriented contribution to the rehabilitation and safeguarding of existing arch bridges in Italy and France.

A key innovation lies in the adoption of advanced Fiber Optic-based techniques for structural monitoring. These technologies offer significant sensitivity, durability, and spatial resolution, enabling the continuous measurement of strain, displacement, and other key indicators of structural behaviour. Their deployment on selected case studies will contribute to significantly improving the state of knowledge regarding the in-service performance of arch bridges, enhancing the accuracy of safety assessments, and supporting the design of targeted retrofitting interventions.

Beyond monitoring, the project will address the experimental validation of retrofitting solutions. Whereas much of the existing literature restricts structural assessment to numerical simulations conducted before and after retrofitting, this research will implement full-scale testing of specimens replicating the static and seismic behaviour of real arch bridges. The integration of laboratory testing, numerical modelling, and field monitoring will therefore provide a comprehensive framework that bridges the gap between theory and practice.

The combination of experimental data and case study analysis will lead to the development of practical guidelines for the classification of typical pathologies in masonry and concrete arch bridges. These guidelines will include recommendations for conducting structural assessments and for selecting appropriate retrofitting strategies, addressing both static and seismic performance, in full alignment with national (e.g., French and Italian) and European structural code provisions. By filling a critical gap, they will provide practitioners with a reliable reference tool that is currently lacking in both technical standards and scientific literature.

Interdisciplinary nature of the research together with the alignment with the CHORAL programme and complementarity expertise of the teams

The proposed project is fully aligned with the objectives of the CHORAL programme, which addresses the many dimensions of cultural heritage. In particular, it focuses on the urgent need to preserve and investigate existing masonry and concrete arch bridges—structures that represent a significant component of the architectural and cultural heritage across the territories of the UNITA Alliance.

Effective conservation and restoration demand a rigorous understanding of both architectural and structural characteristics. This project will leverage the extensive expertise of the participating researchers, who bring proven experience in structural analysis, rehabilitation, and long-term monitoring of masonry and concrete structures.

The interdisciplinary character of the project is evident in the variety of competences involved, spanning architecture, materials science, structural engineering, and heritage rehabilitation. Furthermore, the teams' complementary knowledge is enriched by their direct engagement with emblematic structural sites within their respective countries.

Finally, the dissemination of findings will play a central role: by sharing results and methodologies, the project aims to advance scientific understanding, foster cross-border knowledge transfer, and promote the preservation and restoration of arch and vaulted structures as a shared European legacy.

Output plan including publication and dissemination activities

The dissemination of research outcomes will be pursued through a multi-level strategy. At the international level, results will be published in peer-reviewed scientific journals and presented at leading international and national conferences and workshops. At the local level, dissemination will actively involve bridge managers, heritage protection agencies, governmental bodies, and other stakeholders from the territories under investigation, ensuring that findings are relevant and applicable to practice.

In addition, the project will foster training and knowledge exchange by organizing Summer Schools, Winter Schools, and Erasmus Blended Intensive Programmes, where related topics will be explored with students, researchers, and practitioners.

Finally, depending on the scope and impact of the research achievements, the project results will be consolidated into a final thesis possibly published in an indexed volume, further enhancing their accessibility and long-term visibility.

Estimated schedule

The research will be structured over a three-year period with a clear and progressive sequence of activities:

Months 1–6

- Conduct a comprehensive state-of-the-art review at the international level, with a focus on research carried out within the UNITA alliance and other European contexts.

Months 7–12

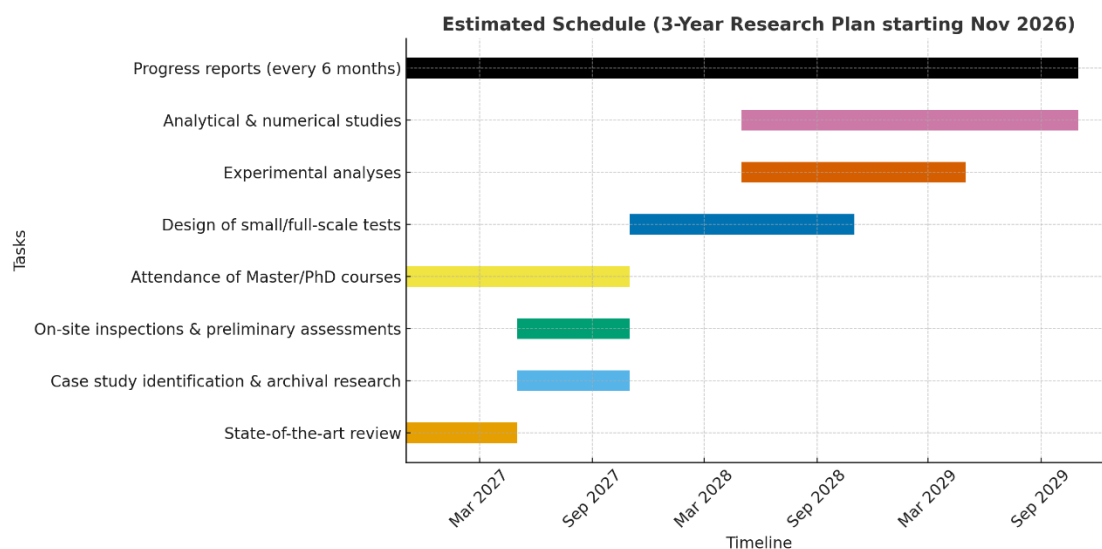
- Identify potential case studies in the territories of the UNITA universities.
- Verify and collect available archival documentation related to the selected structures.
- Perform a critical analysis of archival sources to reconstruct the design and construction history of the chosen case studies.
- Carry out on-site inspections to document local construction practices and begin preliminary structural assessments.
- Attend Master's or PhD courses designed to strengthen the candidate's knowledge in the fields relevant to the project.

Year 2 and Year 3

- Design and conceptualize both small-scale and full-scale tests on representative bridges, defining appropriate monitoring methodologies and strengthening techniques.
- Perform in-depth analysis of experimental results.
- Develop and refine analytical and numerical studies to interpret and validate findings.

Continuous activities (Years 1–3)

- Submission of a progress report every six months, ensuring systematic evaluation and alignment with research objectives.



Gantt-style chart, starting from November 2026