Engineered design frameworks for the seismic retrofitting of existing structures

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A significant portion of existing structures were designed and constructed before the implementation of seismic codes, necessitating seismic retrofitting interventions to ensure their safety and resilience. This situation is particularly prevalent in regions with a long history of construction, where many buildings were erected using outdated engineering practices that did not account for seismic actions. The absence of seismic considerations in the original design makes these structures highly vulnerable to earthquake damage.

Currently, there are no formal methods for designing such retrofitting interventions. This lack of standardized procedures presents a critical gap in the structural engineering field, as engineers must rely only on intuition and experience that may not consistently deliver optimal results. The traditional trial-and-error methods are not only time-consuming but also often lead to over-conservative designs, which can result in unnecessary costs. Moreover, these methods do not guarantee that the retrofitting solutions will meet the desired performance levels under seismic conditions, thus potentially compromising the safety and functionality of the retrofitted structures.

To address this gap, this thesis aims to propose four design frameworks for structural retrofitting. These methods are specifically designed to provide efficient and cost-effective retrofitting solutions for reinforced concrete (RC) frame structures and masonry buildings.

The first three methods are based on the genetic algorithm (GA) approach. The first proposed framework focuses on retrofitting existing RC frame structures, aiming to minimize implementation costs. By leveraging GA's capability to explore a wide search space, this method determines the optimal placement and size of seismic retrofitting, ensuring cost-effective retrofitting configurations. New subroutines have been proposed to be able to analyze structures with deficiencies in terms of both ductility and brittle failure.

The second method extends this approach by optimizing both the position and sizing of retrofitting interventions, thereby minimizing both implementation costs and the expected annual loss. This dual-objective optimization considers the long-term financial implications of retrofitting.

The third framework is tailored specifically for masonry structures, the proposed method introduces a topological optimization algorithm on a structural scale. By considering the unique characteristics and vulnerabilities of masonry structures and the effect of reinforced plasters, the proposed algorithm efficiently determines the optimal reinforcement configuration, enhancing the seismic performance of these buildings.

The fourth method is a performance-based earthquake engineering (PBEE) design procedure for the seismic retrofitting of non-ductile RC frame structures. This method provides a valid tool for risk-targeted design of reinforcement interventions, ensuring that retrofitting efforts meet specific performance criteria under seismic loads. By integrating probabilistic seismic hazard analysis, ground motion selection, and nonlinear dynamic analysis, the PBEE-based framework provides a comprehensive assessment of the retrofitted structure's performance, guiding engineers in making informed design decisions that balance safety, cost, and reliability.

The proposed methods have been validated through a series of case studies involving reference structures. These tests confirmed the generality and robustness of the approaches, demonstrating their effectiveness in providing cost-efficient and reliable retrofitting solutions. For the RC frame structures, case studies included various configurations of shear-critical and ductility-deficient structures, highlighting the flexibility and adaptability of the proposed GA-based methods. The masonry structure case studies involved buildings with different mechanical properties, further validating the topological optimization approach.

The results highlight the potential of these optimization frameworks to significantly improve the safety and resilience of existing structures in earthquake-prone areas, offering a systematic and scientifically rigorous approach to seismic retrofitting design. The proposed frameworks not only optimize retrofitting costs but also ensure compliance with safety standards and extend the service life of the structures.

In conclusion, this thesis presents a suite of design frameworks that significantly advance the state-of-the-art in seismic retrofitting design. By providing robust, flexible, and cost-effective solutions, these methods aim to be indispensable tools for engineers, enhancing the resilience of built heritage and ensuring safety and sustainability in the face of future seismic events, ultimately safeguarding lives and reducing economic losses.