SUMMARY OF THE HABILITATION THESIS

Sustainable Materials and Structural Solutions for Seismic Areas: From Experimental Characterization to Predictive Numerical Modelling

The thesis synthesizes a research programme carried out over approximately 15 years at the "Gheorghe Asachi" Technical University of Iași, organized around a twofold guiding theme: **the development of sustainable construction materials with a low carbon footprint and based on waste valorisation**, and **the characterization of the structural behaviour of the members, connections, and assemblies made of these materials**. The methodology is consistent throughout the work: laboratory and shake-table experimental investigations are systematically complemented by calibrated nonlinear numerical modelling and, in the more recent stages, by machine-learning techniques. The contributions are organized into four chapters.

1. Sustainable cement-based materials

The first chapter gathers the research on durable cementitious materials. An alternative low-carbon-footprint binder — anhydrous calcium sulphate (Kerysten), obtained entirely from industrial by-products (phosphogypsum, lactogypsum, FGD gypsum) — was investigated at replacement levels of 10–40% of the cement volume, on more than 3,500 prismatic specimens and 252 cylinders. Although the compressive strength decreases slightly, the tensile-to-compressive strength ratio improves from about 1/8 to 1/4, and the density drops by 10–19% — structural advantages that are relevant for seismic applications. Pozzolanic and filler materials were also studied: micronized natural zeolite (with the identification of a threshold of about 20% beyond which the pore structure degrades, revealed through an original application of NMR relaxometry corroborated with SEM), expanded perlite as a lightweight aggregate (with a proposed empirical correlation between the dynamic modulus and the compressive strength, and a favourable behaviour at temperatures up to 200 °C), as well as nano-materials — a novel type of capped carbon nanotube that eliminates the need for surfactants and sonication, and the synergistic combination of calcined montmorillonite + TiO_2, studied comparatively for the first time. This chapter also covers the characterization of recycled rubber aggregate concrete and the patented mechanical system for determining the descending branch of the characteristic curve of brittle materials, together with rare data sets on the long-term behaviour (5 and 6 years) of concrete.

2. Analyses on structural members

The second chapter addresses the behaviour of individual structural members through experimental programmes correlated with finite-element modelling. The studies covered short steel-fibre reinforced concrete columns under cyclic loading (separately quantifying the contribution of the transverse reinforcement and of the fibres to energy dissipation), hybrid columns of high-strength concrete and polymer concrete under eccentric loading (identifying the paradox that the reinforcement ratio does not influence the critical crack width), and short rubberized concrete columns confined with AFRP — where two composite layers fully restore the strength lost through aggregate replacement, while the peak strain increases up to tenfold. The research was extended to rubberized concrete beams (40% replacement of the 4–8 mm aggregate) with three reinforcement ratios, highlighting the reversal of the ductility trend at high reinforcement ratios. A second major direction concerns thin-walled cold-formed steel (CFS) profiles and their connections — beam-to-column and column-to-base joints of portal frames, as well as T-joints — for which a methodology for characterizing the finite and nonlinear axial stiffness of the

connections was proposed, demonstrating that the classical assumption of rigid-infinite joints underestimates displacements by a factor of up to ~20.

3. Analyses on scaled models

The third chapter brings together the shake-table tests carried out over a period of about 14 years, covering four structural typologies. A 1:2 scale model of historic unreinforced masonry, representative of the building stock of the Moldova region (solid brick, lime mortar with local calcareous sand), enabled the first systematic mapping of the cracking mechanisms for this regional typology. A full-scale GFRMC prototype validated a lightweight construction system made of glass-fibre reinforced mineral-matrix panels. Reinforced concrete frames at 1:3 scale with short columns, tested within the European project ANAGENNISI, experimentally demonstrated that FRP-confined rubberized concrete reaches an inter-storey drift three times larger than conventional concrete at the same level of excitation. Finally, CFS structures (a Hardell-type structure and a 1:1.2 scale model) confirmed that models with rigid-infinite joints produce erroneous results and allowed the identification of multiple, simultaneous local failure mechanisms specific to these systems — representing the most comprehensive experimental programme on CFS structures carried out in Romania.

4. Numerical analyses

The fourth chapter consolidates the numerical simulation component, presenting the models developed and validated for all the studied typologies: concrete beams and columns (ATENA, LUSAS), scaled reinforced concrete models (Abaqus and a practical strut-and-tie macro-element implemented in OpenSees, which reduces the computation time from five hours to two minutes, with an accuracy of ±5%), and CFS connections and structures (ANSYS, Robot Structural Analysis). The chapter also includes a frontier direction — the use of machine learning: an artificial neural network trained on 3,402 data sets from 243 3D reinforced concrete models subjected to 14 real earthquakes predicts the seismic damage parameters with correlation coefficients above 0.95, outperforming the Random Forest and XGBoost algorithms in terms of generalization capability, and paving the way for automated post-earthquake assessment integrated into monitoring systems.

Original contributions and future directions

The originality of the work stems from the coherent integration of three methodological levels — experimental, numerical, and artificial-intelligence-based — applied consistently from the material scale up to the structural-assembly scale. Among the contributions of a novel character, the following stand out:

- a patented device for obtaining the complete characteristic curve of brittle materials, and the application of NMR relaxometry as a non-invasive method for monitoring the pore structure;
- the structural validation of FRP-confined rubberized concrete, from member to assembly level, with the quantification of the ductility gain (~3–7-fold increase in deformability);
- a methodology for modelling CFS connections with finite axial stiffness, which corrects the errors of the rigid-joint assumption and aligns with the need to revise Eurocode 3 and 8;
- a practical macro-element in OpenSees and a predictive ANN model, both oriented towards performance-based design and the reduction of prototyping costs.

The future directions converge towards the extension of long-term databases, the refinement of interface modelling (bond-slip, frictional contact), the numerical–experimental hybridization through hybrid testing and digital twins, and the integration of machine learning into real-time seismic assessment — all subordinated to the general objective of structures that are sustainable, material-efficient, and seismically safe.