ROBUSTNESS OF MOMENT STEEL FRAMES UNDER COLUMN LOSS SCENARIOS

Teză de doctorat – Rezumat

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1. Abstract

Buildings, like other components of the built infrastructure, should be designed and constructed to resist all actions that may occur during the service life. When the actions are caused by extreme hazards, such as explosion or impact, the structural integrity should be also maintained by avoiding or limiting the damage. Depending upon the type of structural system and class of importance, specific requirements should be met to ensure the structural integrity is assured. In the case of framed buildings, one such requirement is that after the notional removal of each supporting column (and each beam supporting a column), the building remains stable and any local damage does not exceed a certain acceptable limit. This requirement can be achieved by several means, but a combination of strength, ductility and continuity of structural system is likely to provide a high level of protection and safety against extreme hazards.

Steel frames are widely used for multi-storey buildings, offering the strength, stiffness, and ductility that are required to resist the effects of the gravity, wind, or seismic loads. Considered to produce robust structures, seismic design philosophy has been seen as appropriate for controlling the collapse of structures subjected to other types of extreme hazards, too. However, there are specific issues that should be considered to forestall the localized failures, particularly of columns.

The thesis focuses on the evaluation of the structural response of steel frame buildings following extreme actions that are prone to induce local damages in members or their connections. Extensive experimental and numerical studies were used to identify the critical points and to find the structural issues that are required to contain the damage and to prevent the collapse propagation. Four types of beam-to-column joints, which cover most of the joints used in current practice, have been investigated experimentally, and the data was used to validate advanced numerical models. The findings indicated that catenary action substantially improves the capacity of moment resisting frames to resist column loss, but increases the vulnerability of the connection due to high level of axial force. The results showed that bolted connections could fail without allowing for redistribution of loads if not designed for these special loading conditions. Composite action of the slab increases stiffness, yield capacity, and ultimate force but decreases ductility.

Parametric studies were performed to improve the ultimate capacity of joints and implicitly the global performance of steel frame building structures in the event of accidental loss of a column, without affecting the seismic performance and design concepts. Based on validated numerical

models, an analysis procedure was developed for evaluating the performance of full-scale structures to different column loss scenarios considering dynamic effects and realistic loading patterns. Moreover, a design procedure was proposed for verification of the capacity of beam-to-column connections to resist progressive collapse, including design recommendations for each connection configuration.

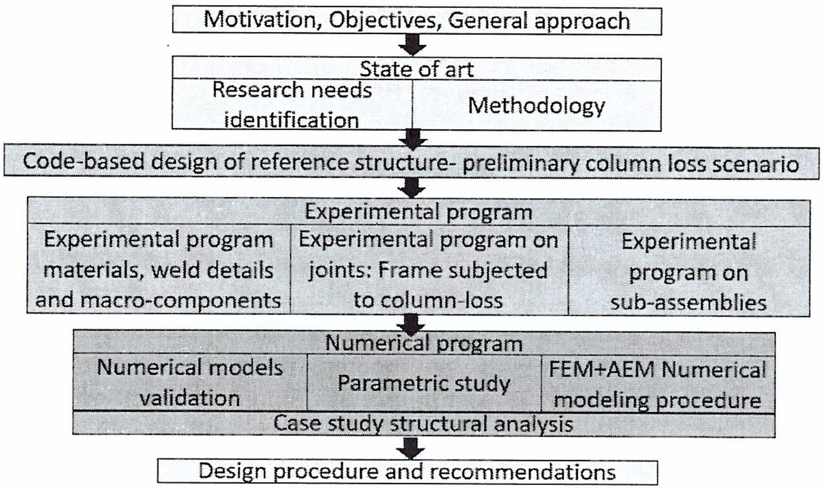

Fig. 1 Main of research activities of the thesis

2. Thesis outline

Chapter 1 presents the motivation and objectives of the thesis, which is developed in the framework of the "Structural conception and collapse control performance based design of multistory structures under accidental actions" reseach project supported by Romanian National Authority for Scientific Research, CNDI– UEFISCDI, project number 55/ 2012 [1]

Chapter 2 presents a state of art of existing studies in the field of progressive collapse of steel frames and introduces the main gaps and needs for the development of the knowledge. An overview of existing design codes is given [2-4]. Experimental testing methods on connection components, 2D and 3D subassemblies and full scale structures is presented [5-8].

Chapter 3 provides detailed information about the experimental program. Based on conventional design rules and requirements and without taking into account the special conditions associated with the accidental design situations, several steel frame building structures were designed, considering various lateral resisting systems located in low and high seismicity areas. One structure was further selected for detailed experimental investigations, i.e. tests on full-scale joints, connection macro-components, and weld details, as well as full-scale frame assemblies. The structure selected for detailed investigations was tested preliminarily for several column loss scenarios within a full-scale simulation using applied element method (AEM) [9]. The numerical model was calibrated using experimental tests from the literature. Four types of connections were designed and detailed for the experimental program on joints, i.e. bolted and welded joints, respectively. From these joints, connection macro-components and weld details were tested using different loading rates and temperature conditions. Static and dynamic push-down tests were performed to evaluate the full response of 3D frame structures in case of an internal accidental column removal, starting with first yielding, plastic mechanism, and failure mode. [10-14]

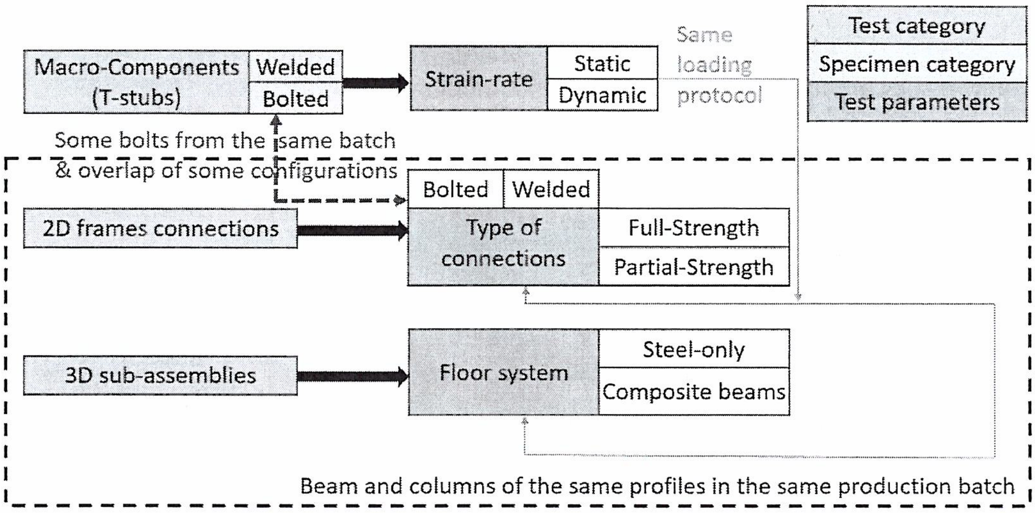

Fig. 2 experimental testing program

Chapter 4 presents the numerical simulations program. Experimental data obtained in the previous chapter were used for validating the numerical models. For weld details and connection macro-components, finite element models were constructed and validated to determine the response. Finite element analyses were performed for optimizing the response and improve the ultimate capacity. For joints and 3D assemblies, both finite element models and applied element models were constructed and validated. Several case study buildings were used in the numerical program to get insights into the response of multi-storey steel frames in the event of column loss and to develop strategies to mitigate the progressive collapse. [15-17]

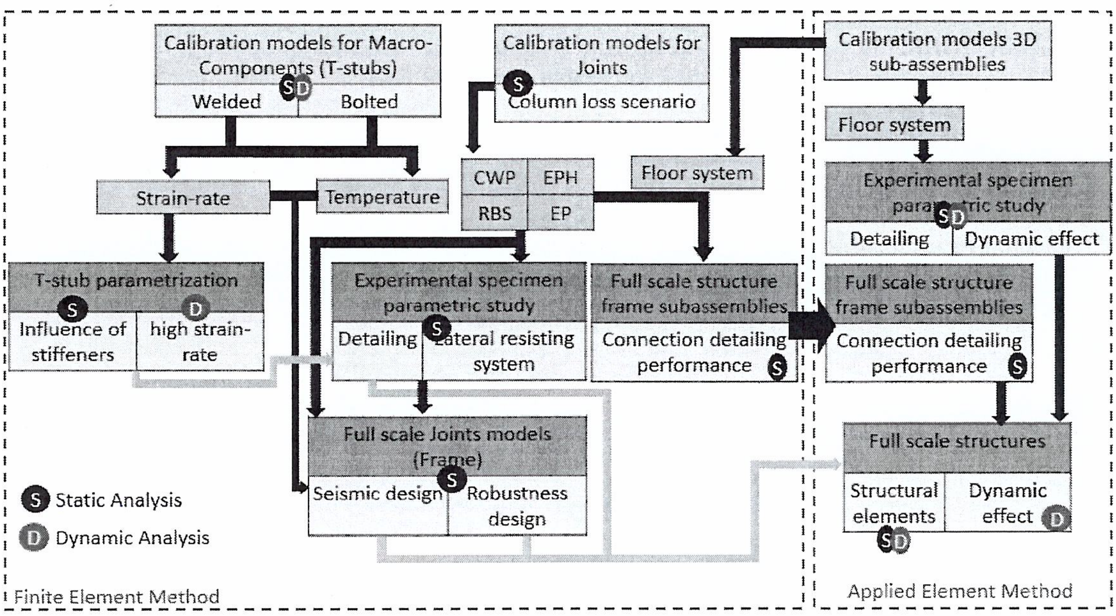

Fig. 3 Numerical program framework

Chapter 5 provides recommendations for designing steel frame buildings with improved robustness and resistance against progressive collapse and in general for cases when accidental actions can lead to heavy local damage (partial or complete loss of some members). The recommendations address mainly the design and detailing of beam-to-column joints, but also the selection of structural analysis techniques (static, dynamic) and types of structural systems and construction materials when progressive collapse resistance is addressed. [3]

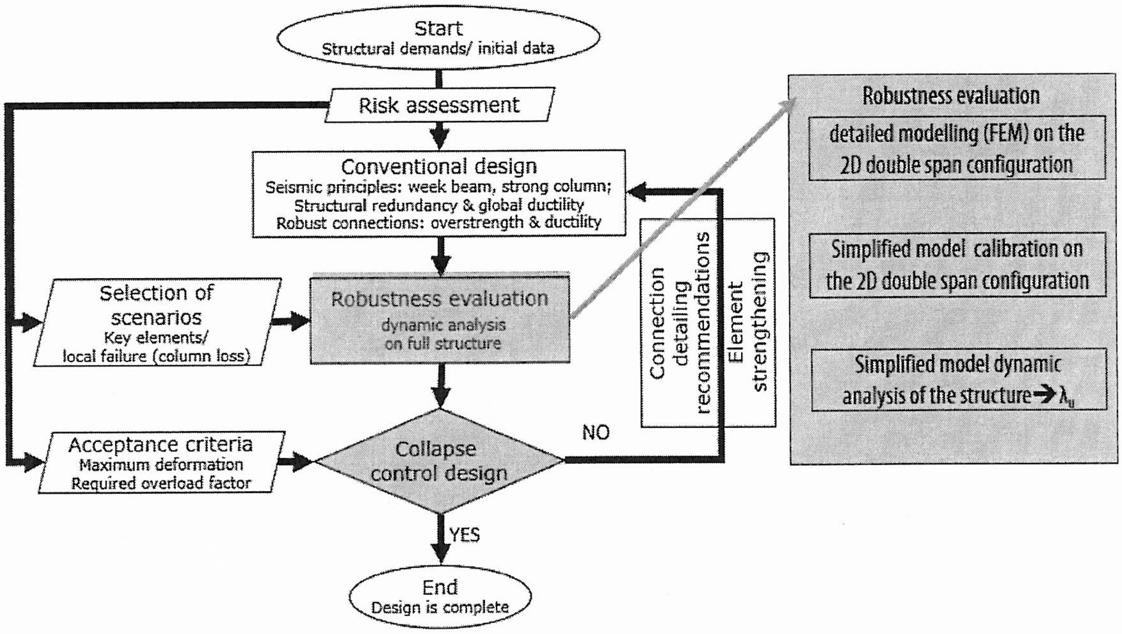

Fig. 4 Flowchart for robustness design of MRF structures and connections

Chapter 6 presents the results and main contributions and maps the direction for future research works. The extensive experimental program, coupled with advanced numerical simulations allowed the development of beam-to-column connections with improved robustness for extreme loading conditions. The application of refined nonlinear models to case study buildings demonstrated the efficiency of the solutions compared to existing knowledge and practice.

References contain thesis, journal and conference papers, research and investigation reports, and standards that contain information presented in the thesis. Other technical information sources, computer program software and grant details are also presented here.

Annexes give detailed information about the experimental program, the construction, and validation of numerical models, the design of case study buildings and results of numerical simulations.

3. Acknowledgement

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