SEISMIC PROTECTION OF BUILDING FRAMED STRUCTURES WITH BUCKLING RESTRAINED BRACES

PhD Thesis– Summary

for obtaining the scientific title of Doctor of Philosophy at the
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1. Abstract

The seismic protection of building structures located in earthquake-prone areas is of a critical importance in preventing human losses and material damages in case of an earthquake. During the last decades, several earthquake-resistant structural systems were proposed to reduce and control the damage of buildings during a seismic event. Such systems use dissipative elements (structural "fuses") to protect the structure. An example of such fuse is the buckling restrained brace (BRB). In comparison to the conventional braces, the BRBs proved to have enhanced features: no buckling in compression, stable and quasi-symmetric cyclic response, capacity to dissipate a large amount of energy.

BRBs have a great potential for seismic applications due to their hysteretic performance. However, in Romania there are no project applications yet, even though design provisions for buckling restrained braced frames (BRBFs) were introduced in the national seismic design code starting with January 1st, 2014. It might be the proprietary character of the commercialized BRB solutions or the experimental qualification required by the design code that limits their wide adoption. The lack of experience of structural engineers in designing BRBs/BRBFs is also considered to limit the large applicability of BRBs.

Therefore, the main objective of this thesis is to pre-qualify a set of BRBs for typical low-rise and mid-rise steel framed buildings located in Romania. The pre-qualification will eliminate the necessity of project-based experimental validation for future projects. The research program was intended to clear the way for a rapid adoption of the BRBs into the design practice by developing pre-qualified technical solutions and by transferring the "know-how" on the design of BRBs to the industry.

The pre-qualification of BRBs through numerical testing, using the procedure proposed in this thesis, required the development of a complex numerical model, able to simulate the behaviour of the active steel core of the BRB in the post-elastic domain under cyclic loading regime. There is few information in the technical literature regarding this subject, and the available ones are briefly presented, with results, in general, not relevant. Therefore, the development and validation of this numerical model represents an important achievement of this thesis.

This thesis is structured on eight chapters and presents the pre-qualification program of BRBs, which included both experimental tests and pre/post-tests numerical simulations, and a study case application of BRBs on a steel framed building. Detailed description per chapter are

presented below.

2. Thesis outline

Chapter 1: Introduction

The first chapter presents the motivation, the objectives and the research framework of the thesis. The need to overcome the problems related to the application of BRBs motivates this thesis. The main objective is to pre-qualify set of BRBs as to clear the way for a rapid adoption of the BRBs into the design practice. The main research framework of the thesis is a National research project, entitled: "Implementation into Romanian seismic resistant design practice of buckling restrained braces", acronym IMSER.

Chapter 2: BRB – state of knowledge

The second chapter presents the state of knowledge on BRBs with the emphasis on the principle of work, history of development, applicability, advantages and disadvantages. The performance of different bracing systems are compared (BRBF vs. CBF) from the point of view of cost savings. Critical evaluation of existing BRB technical solutions will reveal the optimal technical details to be used for the development of the new BRB solutions. Existing design regulations are also presented and needs for further research and development are set.

Chapter 3: Development of technical solutions

Chapter three presents the development of both "conventional" and "dry" BRBs solutions. Two values of resistance, 300 kN and 700 kN, are proposed for pre-qualification. Both numerical and experimental pre-tests are used as to obtain the conceptual BRB solutions. Four typologies are proposed, two "conventional" and two "dry". Bolted connections are proposed for the BRBs and special detail is used to enhance their cyclic performance.

Chapter 4: Experimental tests for pre-qualification of BRBs

The experimental program including the pre-qualification tests on BRBs and the tests on component materials are presented in chapter four. 14 full-scale BRBs are cyclically tested, and different detailing was used for the specimens as to investigate the influence of a series of parameters on the cyclic performance of the BRBs. Based on the performance criteria, the pre-qualified BRB solutions are selected, and design recommendations are given.

Chapter 5: Post-test numerical simulations

Chapter five presents the results of two sets of simulations that were performed as to assess: (1) the accuracy of different material models in reproducing the behaviour of the steel material under monotonic and cyclic loading; (2) the influence of several parameters (that could not be observed/measured during experimental tests) on the cyclic response of BRBs.

Chapter 6: Design recommendations

Based on the experimental and numerical results obtained on BRBs, design recommendations are given for the pre-qualified solution. Applicability limits of the design procedure are also given to provide the new BRBs with a high level of reliability.

Chapter 7: Performance-based design of BRBF

Chapter seven presents an optimization study of the core geometry. A study case steel framed building equipped with BRBs of different geometries is considered for this investigation. The influence of the strain level in the core on the seismic performance of the building is assessed and additional design recommendations for BRBs are given. The influence of different column-base supports on the seismic response of the building is assessed and solutions are proposed to improve the response.

Chapter 8: Conclusions

A synthesis of the conclusions of the thesis, as well as the contributions of the author and valorisation of research are presented in chapter eight. Further research directions are set as to provide a continuity of the studies developed within the thesis.

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 numerical model developed in OpenSees and used for the numerical analyses on buckling restrained braced frames, also, the accelerograms are presented.

3. Acknowledgement

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