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A low-tech dissipative buckling restrained brace. Design, analysis, production and testing

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ABSTRACT

This work aims to foster the mass use of buckling restrained braces, mainly in developing countries. To reach this goal, two major objectives are pursued: (i) to contribute to a better understanding of the structural behavior of such dissipators and (ii) to propose cheap and simple yet efficient devices, suitable for the intended applications. Such devices should be patent free. The research approach consists of three consecutive stages: (i) designing, producing and testing individually short length dissipators, (ii) taking profit of the gained experience to design, produce and test individually four larger prototype devices (near 3000 mm long) and (iii) designing, producing and testing on subassemblies, a number of full scale dissipators. The two first stages are completed while the third one is in progress; this paper concentrates on the second stage. The considered devices consist basically of a steel cylinder as dissipative core and a steel tube filled with mortar as buckling restrainer casing. The design and production issues are accounted for in an integrated way and all the adopted technical solutions are explained. A numerical analysis of the buckling behavior is carried out; it allows formulating design recommendations. The experiments consist of imposing on the prototype devices axial cycling strain up to failure. The results of the tests are described and discussed; they show that the devices performed satisfactorily. The main conclusion of this work is that it is possible to obtain a reasonably cheap, efficient, robust, low maintenance and durable prototype device requiring only a low-tech production process. Further research needs are identified.

1. Introduction

Energy dissipators are a convenient option for earthquake-resistant design of buildings and other civil engineering constructions since they absorb most of the input energy, thus protecting the main structure from damage even under strong seismic motions [1,2]; many applications have been reported [3]. Several types of devices have been proposed; those based on plastification of metals (commonly termed as hysteretic) are simple, cheap and reliable and have repeatedly shown their usefulness. Among them, the buckling restrained braces are one of the dissipators more used for seismic protection of building frames [4,5]. They consist of slender steel bars connected usually to the frame to be protected either like concentric diagonal braces as shown by Fig. 1.a or like chevron braces as shown by Fig. 1.b. Under horizontal seismic motions, the interstory drifts generate axial strains in such steel bars beyond their yielding points; their tension–compression cycles constitute the hysteresis loops. The buckling of these bars is prevented by embedding them in a stockiest encasing. Such encasing is usually formed by steel elements [6,7] commonly filled with mortar (see Fig. 2). Some sliding interface between the steel core and the surrounding mortar is required to prevent excessive shear stress transfer, since it would reduce the longitudinal stress in the core thus impairing the energy dissipation; also, as this interface involves some clearance between the core and the mortar, such a gap is required to allow the Poisson expansion of the core during compression.

The buckling restrained braces posses several relevant advantages compared to other hysteretic devices:

- The ratio dissipated energy/added material is the highest in the comparative devices [8]; the added material includes dissipators, bracing and connections. The degree of plastification is uniform along the whole body of the core.
- These dissipators constitute themselves as a bracing system and no additional braces are required to connect each device to the main frame.

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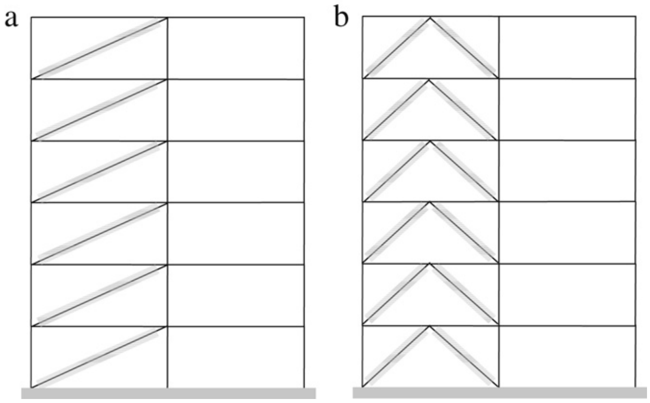

Fig. 1. Building frames protected with buckling restrained braces.

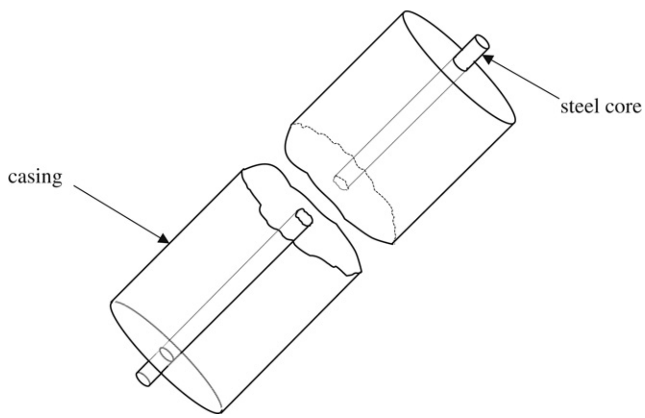

Fig. 2. Common type of buckling restrained brace.

- A relevant experience is available since a number of individual and subassemblage tests have been carried out [7,9–20] and many realizations have been reported, mostly in Japan [6], Taiwan [7], Canada [21] and the United States [9]. Preliminary versions of design codes have been proposed [22–24] and many references about design procedures are available [14,16,17,25–31].
- Since the dissipative part of the device can encompass nearly the whole length of the brace, the required strain is rather low. Therefore, the plastic excursion is rather moderate, possibly providing high fatigue resistance.

In spite of the relevant existent background about the buckling restrained braces, there are still some open questions which require further research:

- **Design and production**. Although a number of devices based on axial plasticity of steel bars are commercially available, no full details about them have been reported, perhaps partially for confidentiality reasons. In particular, the solutions for the sliding interface between the steel core and the mortar have been reported only scarcely [7,16,17] in the technical literature. Also, most of the relevant production issues have not been deeply discussed.
- **Buckling analysis**. The buckling design of the mortar-steel coating is based usually on simple second-order models [9,17]. Some of their parameters are not usually selected from the actual parameters of the device but merely from semi-empirical considerations; hence, the obtained results cannot be very accurate and it is uncertain than they are on the safe side. In other words, only over-conservative designs of the casing are feasible and it is even doubtful that the actual safety factor is greater than 1.
- **Experiments**. A number of tests have been carried out, both individually and on subassemblies accounting for the main frame. Perhaps the only relevant thing missing is extensive information about the inner final condition of the devices.
- **Structural behavior**. The structural behavior of the device is rather complicated because of the coexistence of several coupled issues, mainly: (i) joint behavior of three materials (inner and outer steel, mortar and the sliding interface), (ii) plastic cyclic behavior of the core, (iii) partial sliding between the core and the encasing mortar and (iv) large strains and displacements. A reliable and accurate numerical model considering these issues has not been reported. This omission requires that the design is based on over-conservative approaches and prevents the proposal of innovative and daring solutions.
- **Effectiveness**. Although several parametric studies have been reported in the technical literature [32,33], their authors still indicate a number of open questions. It is noted that most of the existing studies refer to steel buildings while this research is rather oriented to concrete frames, very common in developing countries.

This work belongs to a research project aiming to promote the mass use of patent free buckling restrained braces for seismic protection of buildings in developing countries. The research approach consists of: (i) designing, producing and testing individually five short length dissipators (about 400 mm long) [34,35], (ii) taking advantage of the gained experience to design, produce and test individually four larger prototype devices (near 3000 mm long), (iii) deriving a simplified model of the buckling behavior of these devices, (iv) developing a complex numerical model of their structural behavior, (v) designing, producing and testing on subassemblies a number of full scale dissipators and (vi) performing a numerical parametric study about the seismic efficiency of such devices. The first three stages are completed, while the last three are still in progress. This paper deals with the second and third stages, which correspond to the first three open questions. A description of the research follows; such description is organized according to the aforementioned questions.

- **Design and production**. A buckling restrained brace dissipator is designed and a number of prototypes are produced; such device is rather similar to the existing ones (see Fig. 2). Main concerns of the design are: (i) efficient, simple, robust, low maintenance and durable device, (ii) low cost, (iii) simple manufacturing and (iv) easy to find materials.
- **Buckling analysis**. A simple yet reasonably accurate second order analysis is performed. The geometrical imperfections and the nonlinear behavior of the core are explicitly considered in a simplified way.
- **Experiments**. Individual testing has been carried out in the University of Girona, Spain; the experiments consist of cycling axial loading until failure.

2. Design and production

Beyond efficiency, the following qualities are sought in the proposed devices:

- **Simplicity**. The device should be robust, durable and virtually maintenance-free.
- **Low cost**. It should be kept in mind that the use of energy dissipators has to compete with other solutions and that in developing countries the economical issues are crucial.