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Cyclic behavior of buckling-controlled braces

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ABSTRACT

A parametric study is presented to quantify essential factors influencing cyclic behavior of a steel buckling-controlled brace (BCB) with a tube carrying axial load surrounded by an outer tube to control buckling of the load-bearing tube. A small-scale experiment helped observe overall cyclic behavior, and develop finite-element models for numerical simulations. The model-based simulations identified the interaction of the friction, gap and thickness ratio between the two tubes as the essential factor. The paper concludes that (1) the gap is a sensitive parameter influencing local and global buckling. The smaller the gap, the less likely the local and global buckling will occur, but the more participation of the outer tube in load bearing due to adverse interaction between the two tubes; (2) Friction between the two tubes is a very delicate factor because its impact on the cyclic behavior of BCB varies depending on thickness ratio and friction; (3) Thickness ratio of the two tubes decides the effectiveness of controlling buckling. The thickness ratio of 1.0 is sufficient to control global buckling, but a larger than 1.0 ratio is needed to control both local and global buckling; (4) Interaction among the gap, friction and thickness ratio is strong, and shall be considered in design; and (5) Optimal performance results from a system with smallest gap possible, low friction, and heavier outer tube. Some less optimal but lower costly design combinations may have moderate gaps and various outer tube sizes to control brace buckling within targeted drift limits in performance-based design.

1. Introduction

Global buckling of conventional braces in concentrically braced frames has been traditionally designated as a viable energy-dissipation mechanism. One of the major concerns with such mechanism is the premature fracture of the brace due to combined global and local buckling in the brace when subjected to cyclic loadings during an earthquake ground motion. In addition, substantial difference in the tension and compression strengths of the brace imposes significant demand on brace-intersected beams and beam-to-column connections. The attempt to prevent global buckling in a conventional brace has resulted in many forms of buckling restraining mechanisms, all of which share the same simple concept of providing nearly continuous lateral support to the brace along its length. It is essential for such support not to participate in axial force resistance of the brace. The most popular buckling-restrained brace in current practice consists of load-bearing steel core embedded in mortar inside a steel tube. The mortar together with the steel tube formulates a restraining mechanism that provides a continuous lateral support to the steel core throughout its length. The steel core is coated with un-bonding material to minimize the friction between the core and surrounding mortar so that the participation of the restraining mechanism in resisting axial force is limited. Numerous studies have shown that this type of un-bonded buckling-restrained brace (UBRB) effectively avoids buckling of the steel core under compression, resulting in the same initial strength in tension and compression. Steel frames with UBRB have been used for seismic design and retrofit in buildings and bridges [1–5]. The concerns with the UBRB include its high initial cost and difficulty in post-earthquake inspection. In addition, the compressive strength is significantly larger than tensile strength in a UBRB subjected to large inelastic deformation, which might adversely impose negative bending moment in brace-intersected beams.

Studies on all steel components as buckling restrainer (BR) appeared as early as 1993 [6] and 1994 [7]. The all-steel buckling-restrained brace (BRB) employs only steel shapes for both load-bearing and buckling-restraining functions. Most common all-steel BRBs consist of a steel plate as load-bearing core sandwiched between two back-to-back channels or the alike that are bolted or welded together along the length as BRM, herein referred to as Sandwiched Plate BRB (SP-BRB).

Eryasar et al. [8] tested a group of 12 small-scale SP-BRBs. No gap was designed in the tested specimens, and a layer of greasy polyethylene film was applied between the steel core plate and its buckling restraining system to avoid significant friction between them. The specimens showed stable hysteretic behavior without any global buckling beyond design story drift ratio. However, the stable cyclic behavior

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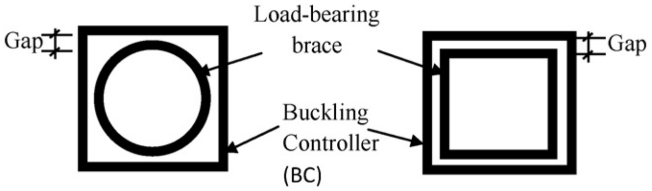
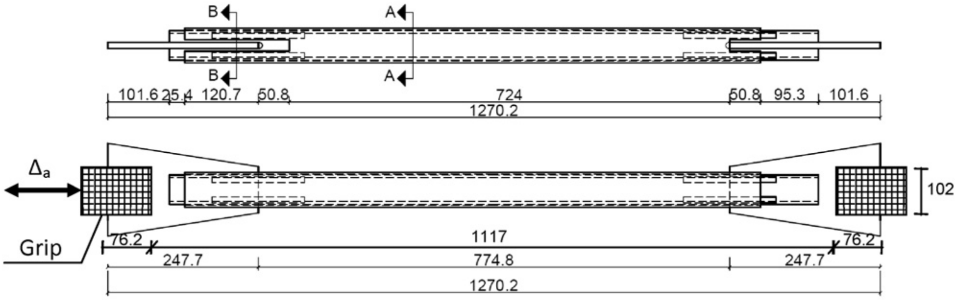


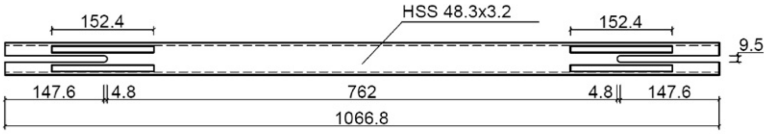
Fig. 1. Cross sections of tube-in-tube buckling-controlled brace (TinT-BCB).

Fig. 3. Test setup.

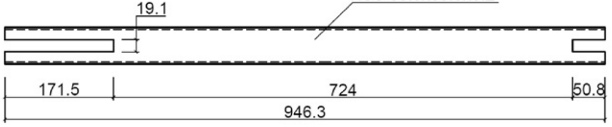
apparently resulted from simply applying polyethylene film as a temporary un-bonding coating for the laboratory testing purpose in order to avoid addressing fundamental issues of effects of friction, gap and their interaction on cyclic behavior of the specimens. Note that this type of coating has not been proven effective over time. It is not clear how the brace would behave without friction-reducing coating. The SP-BRB was compared with concrete-filled BRB experimentally by Tremblay et al. [9]. The authors included an initial gap between the steel core plate and BR in the SP-BRB specimens. Fracture was observed in a SP-BRB with larger initial gap. It was concluded that keeping the gap between the core and BRM as small as possible, together with a stiff BRM component and providing a low-friction contact between the core and BRM, would result in an optimal performance of the SP-BRB. The study confirmed that the local buckling tendency of the steel core plate is extremely sensitive to the gap value as well as impact friction. The paper does not provide information on how to determine the size of the gap, BRM stiffness, and type of low-friction surface. In other words, the interrelationship among the gap, BRB stiffness and contact friction coefficient is not addressed in order to achieve an optimal all-steel BRB. In addition, the b/c ratio equal to 10 was kept for all specimens in [9]. A parametric study was conducted on the SP-BRB using finite element simulations by Hoveidae et al. [10]. Three different gap amplitudes were introduced to the BRB under cyclic loading up to a ductility of 10. With the gaps, the steel core plate having a b/t ratio of 10



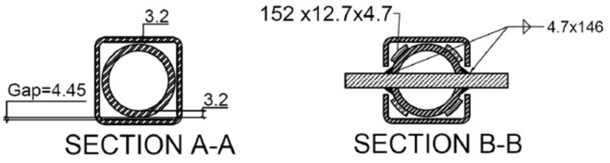
(a) Side view of the test specimen



(b) The main brace



(c) The buckling restrainer (outer tube)



(d) Section view of the specimen

Fig. 2. Drawings of the tested TBRB specimen (units: mm; not to scale).