Journal of Constructional Steel Research 138 (2017) 621–632

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Development of a self-centering buckling restrained brace using cross-anchored pre-stressed steel strands

Haishen Wang [a], Xin Nie [a], Peng Pan [a,b,*]

[a] Department of Civil Engineering, Tsinghua University, Beijing 100084, China
[b] Key Laboratory of Civil Engineering Safety and Durability of the China Education Ministry, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 5 April 2017
Received in revised form 20 July 2017
Accepted 26 July 2017
Available online xxxx

Keywords:
Self-centering buckling restrained brace
Cross-anchored
Pre-stressed steel strands
Energy dissipation
Finite element analysis

ABSTRACT

A refined self-centering buckling restrained brace (SC-BRB), which provides good energy dissipation and self-centering ability for structures, is proposed. The SC-BRB system is made of two tubes and core plates. To improve the energy dissipation performance under earthquake excitation, the low-yield-point steel core plates are restrained by the middle and outer tubes. The self-centering capacity is provided by a group of pre-stressed steel strands coupled with two cover plates and the middle and outer tubes. Cross-anchored technology is used to improve the deformability of the pre-stressed strands, which also improves the deformability of the SC-BRB. To study the energy dissipation performance and self-centering ability of the proposed SC-BRB, two specimens using cross-anchored pre-stressed strands were fabricated and tested. Finite element analysis using ABAQUS was carried out to simulate the behavior of the SC-BRB. Based on the finite element analyses, a parametric study was conducted by using the initial pre-stress value and cross-section area of the steel core plates as design parameters to obtain the optimal values of these two parameters. The SC-BRBs with the appropriate parameters exhibited good energy dissipation and self-centering capacity up to a deformation that equals 1% of the brace length. The finite element analysis results agree well with the physical test results, and the two design parameters are interrelated and both have significant effects on the energy dissipation and self-centering ability of the SC-BRB.

1. Introduction

Residual deformation is an important index used to characterize the earthquake resilience of building structures, and has been widely used in recent years [1,2]. Conventional structures, e.g. shear wall structures, reinforced concrete frames, and steel braced frames dissipate energy by forming plastic hinges at the conventional structural components [3–7]. These plastic hinges induce significant residual deformations, which extend the post-earthquake downtime of the building and lower its earthquake resilience. Previous research [8,9] found that self-centering energy dissipative (SC-ED) braces can minimize the residual deformation and provide adequate energy dissipating capacities, providing an effective way of solving the residual deformation problem.

The performance of SC-ED braces depends on two subsystems: the self-centering (SC) system and the energy dissipative (ED) system. The energy dissipative (ED) system is generally comprised of friction damping devices, also called friction dampers, which dissipate energy by the relative motion of friction plates. Friction dampers have many advantages such as excellent hysteretic performance, compact size, and easy installation requirements, and are therefore widely used as energy dissipative devices [8–12]. However, concerns have been raised as to the durability of friction dampers which can be reduced as a result of stress relaxation and metal infiltration [13,14].

A buckling restrained brace (BRB) is a type of metal yield damper which is widely used because of its stability and cost effectiveness. The diagram of a typical BRB (Fig. 1) shows the core plates and restraining units. The restraining units prevent the core plate from buckling, thus significantly increasing the compressive strength and energy dissipation capacity of the brace [15–17].

Recent studies combined the BRB and SC systems to produce the SC-BRB, a new energy dissipation device. David [18] and other researchers [19,20] developed a SC-BRB combining NiTi-SMA rods and a relatively small BRB. Their test results show that although costly SMA rods were used in the design, the residual deformation of the device was about half the maximum deformation of the brace, indicating that full self-centering behavior was not achieved. Another SC-BRB was developed by Zhou et al. [21]; this brace combined Basalt Fiber Reinforced Polymer (BFRP) strands and steel core plates restricted by inner and outer tubes. This SC-BRB is much simpler and effective than the previous one; however, the anchorage of the BFRP strands was too long, which significantly decreased the effective length of the BFRP and limited its deformability. In addition, the area near the anchorage was prone to

* Corresponding author at: Department of Civil Engineering, Tsinghua University, Beijing 100084, China.
E-mail address: panpeng@mail.tsinghua.edu.cn (P. Pan).

http://dx.doi.org/10.1016/j.jcsr.2017.07.017

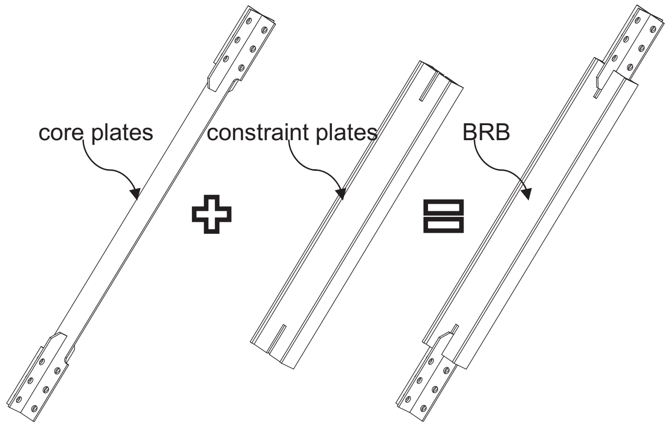

Fig. 1. Basic components of BRB [14].

peeling fracture. The above features lead to a relatively small deformation capacity, no more than 1% of the brace length.

Pre-stressed steel strands are by far the most established and cost-effective way to apply pre-stressed forces [22]. However, the elastic deformation of steel stands may not be large enough; this can significantly restrict the deformation capacity of the SC members. A cross-anchored system, which can double the deformation capacity of the SC members using pre-stressed steel strands, was proposed and validated by Chung [12].

In this paper, a refined SC-BRB using cross-anchored pre-stressed steel strands, which is the main difference between the refined SC-BRB with other SC-BRBs [18,21], is presented. This SC-BRB has a compact structure and is easy to fabricate. The proposed SC-BRB can be installed to the structure through bolting or welding. Considering in-situ quality control and possible replacement post-earthquakes, bolting is recommended. Two full-scale SC-BRB specimens with slightly different design features were fabricated and tested to validate the effectiveness of the proposed SC-BRB. Finite element analysis was carried out to simulate the behavior of the SC-BRB. Parametric analysis was conducted to investigate the effects of the two main parameters influencing the SC-BRB behavior – the initial pre-stressed forces and the size of the core plates – on SC-BRB behavior [21].

2. Structure of the cross-anchored SC-BRB

The cross-anchored SC-BRB is made of steel tubes, steel plates, and pre-stressed steel strands. The two SC-BRB specimens, i.e. Specimen 1 (S1) and Specimen 2 (S2), are illustrated in Fig. 2. The two specimens have a similar structure but differ in some design features. Fig. 3 illustrates the main assembly stages of Specimen 1. The assembling process can be divided into six steps. Step 1: the core plates are welded onto the middle tube, the restricting plates are welded alongside the core plate, and the end plate and cross plate are welded to the end of the middle tube. Step 2: the limit plates are welded to the inner wall of the outer tube at the specified positions. Step 3: the middle tube is inserted into the outer tube until the end of middle tube touches the limit plates, then the core plates are welded to the inner wall of the outer tube. Step 4: the steel strands are passed through the inner tube: four strands are anchored on one end, then the inner tube is pushed into the middle tube and the other four strands are anchored on the other end of the

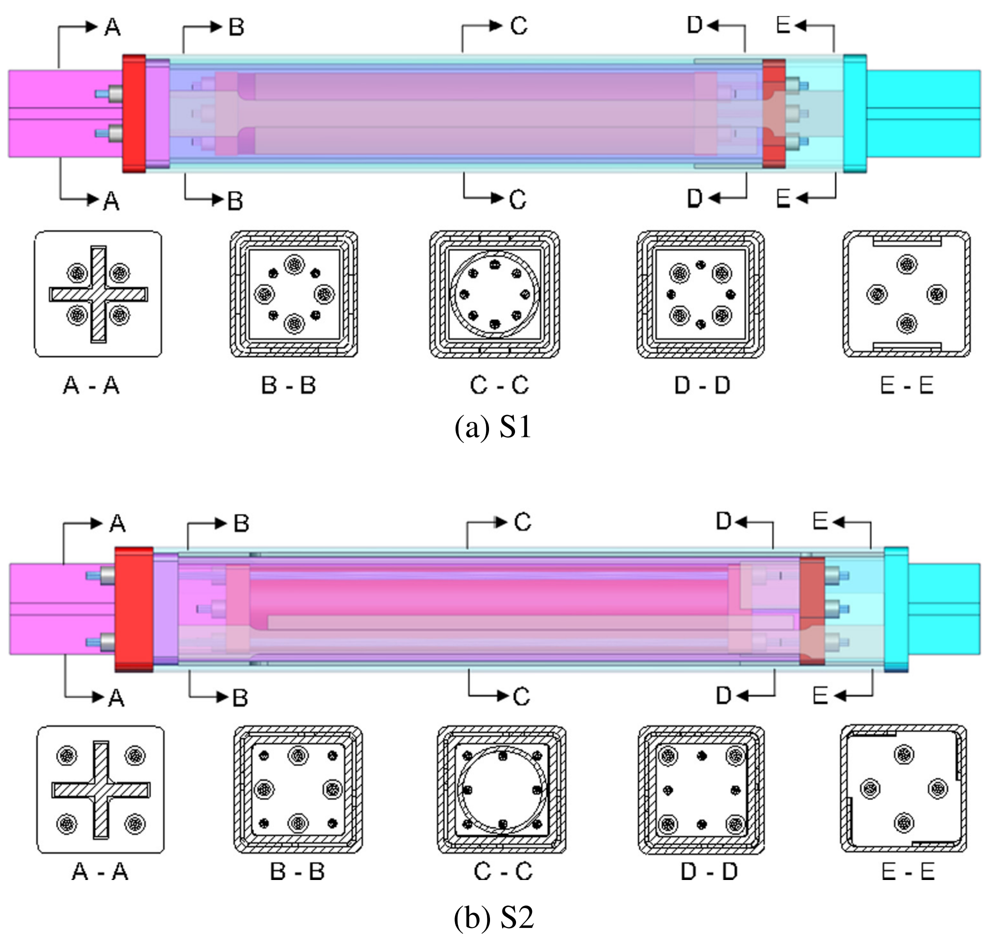

Fig. 2. Two specimens of cross-anchored SC-BRB.