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Experimental research of assembled buckling-restrained braces wrapped with carbon or basalt fiber

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ABSTRACT

A new assembled buckling-restrained brace (ABRB) wrapped with carbon or basalt fiber cloth is proposed. It has the following advantages: 1) it can be disassembled by cutting the fiber cloth; 2) it is easy to inspect and repair the core plates after destructive earthquakes; 3) the outer fiber material also serves as a corrosion resistance to the outer steel tube. A total of eight ABRB specimens were tested under quasi-static axial loads. The test results indicate that the ABRB is capable to undergo fully-reverse yielding cycles without loss of stiffness and strength with sufficient ductility and energy absorption capacity. Multi-wave buckling occurred on the core plates of ABRBs resulting in "jumped" hysteretic curves in compression stage. ABRB specimens fractured in the middle of the core plate elements when a loading protocol included increasing deformation amplitudes with additional fatigue cyclic loading; while when the loading protocol consisted of increasing deformation amplitude cyclic loading without maximum amplitude limit, rupture of the ABRB specimens occurred at the junctions of yielding segments and non-yielding segments of core plate. When a pair of restraining members of an ABRB are connected and restrained with fiber cloth, the assembled constraint mechanics can resist the lateral thrust exerted by core plate. The nonlinear finite element analysis results show good agreement with the experimental data. Both the results from the experiment and numerical simulation show that the proposed ABRBs can satisfy the performance requirements for the BRB components and provide a beneficial alternative for BRB fabrication and application.

1. Introduction

Buckling restrained braces (BRBs) are made from encasing a core steel cross-shape or flat bar member into a tube and confined by infill concrete. The steel core member, whose tension and compression yield capacity are almost identical with each other, is designed to resist the axial forces. An unbounding material or clearance is commonly assigned between the core member and the infill concrete with the aim of reducing the bonding-induced friction. The infill concrete together with the outer steel tube encasement provide sufficient flexural strength and stiffness to prevent global buckling of a brace, and have a positive effect on the resistance of local buckling. Previous research and engineering applications have shown that BRBs can improve the seismic performance of conventional buildings [1–3].

Numerous experimental and numerical studies have been conducted to examine the mechanical property, stability performance and hysteretic behavior of different types of BRBs. For example, Watanabe et al. [4] addressed the effect of outer tube configuration on overall load capacity of BRBs. Chen et al. [5] tested the hysteretic behavior of the BRBs made of low yield point (LYP) steel. Through a comprehensive test involving 20 specimens, Wang et al. [6] presented a reliable constitutive model of LYP steel applied in the simulation of BRBs. Lai et al. [7] proposed a new type of BRB employing double steel cores encased in twin steel tubes and infill concrete. Black et al. [8] reported the results from a comprehensive component testing program involving five BRBs with various configurations and verified the reliability and practicability of the BRBs (known as 'Unbonded Braces'). Jia et al. [9,10] experimentally investigated the cyclic behavior of the BRBs with H cross section unrestrained segments and compared them with that with cruciform cross section unrestrained segments. Genna and Gelfi [11] conducted experimental and numerical studies on the lateral forces exerted by the core plate of BRBs. To investigate core plate multimode buckling phenomenon, Wu et al. [12] conducted cyclic loading tests and finite element analyses on six all-steel BRBs under different loading patterns. The good strength and stiffness, hysteric characteristics and energy dissipation capacity shown in the above studies have accelerated the application of BRBs in civil engineering [1].

Recently, there has been an increasing focus on the concept of assembled BRBs (shortly named as ABRBs hereafter). Unlike the conventional integral BRBs, the ABRBs can be repaired or replaced conveniently by disassembling outer restraining members after core plates being damaged in earthquakes. Besides, the subassemblies of ABRBs can be fabricated and delivered separately for on-site erection

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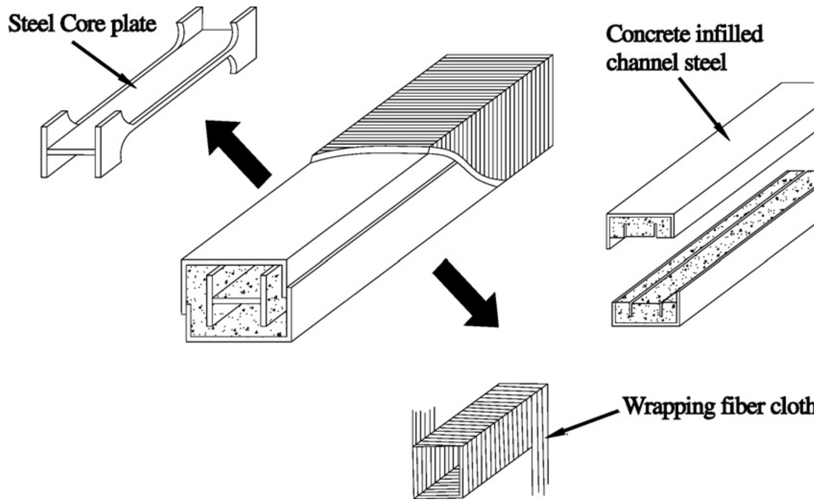
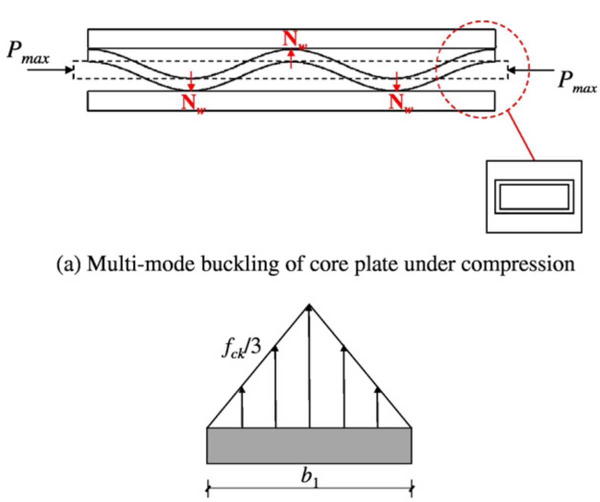


Fig. 1. Proposed assembled buckling restrained brace.

and are thus valuable for quality control in practical use. Several studies have been conducted on the development of different types of ABRBs. For example, Iwata and Murai [13] developed an ABRB by sandwiching a core plate with a pair of welding mortar-filled channel steel as a restraining part. Chou and Chen [14] presented the experimental and numerical results on the performance of the BRBs composed of a steel core plate and two identical restraining members which sandwich the core plate with fully tensioned high-strength bolts to prevent core buckling. The subassemblies of ABRBs are commonly connected with welded or bolted attachments. Eryasa and Topkaya [15] conducted a seismic test program performed on 12 steel-encased BRBs for examining the effects of bolt pretension, core-to-encasing attachment details, aspect ratio of core segment and imperfections due to manufacturing on the hysteric performance of BRBs. Hoveidae and Rafezy [16] presented finite element analysis results of the hysteric behaviors of one kind of full-steel ABRBs considering different buckling restraining mechanisms. Among the available ABRBs, the aluminum alloy has also been used since it is lighter than the normal steel. A kind of high-performance BRBs with stoppers that are bolt-assembled was proposed by Usami et al. [17], and the effect of stoppers on the low-cycle fatigue performance were experimentally and numerically examined [18]. Wang et al. [19] proposed an extruded aluminum alloy core plate ABRB, which can avoid the use of welding and complex BRB ends in previous BRB research. In the study of Dusicka et al. [20,21], an aluminum alloy core was adopted for a new type of ABRB constrained with the glass fiber reinforced polymer pultruded tubes used as the assembled buckling-restraint mechanics. Deng and Pan [22] proposed GFRP steel BRB restrained with four GFRP pultruded tubes, which are tied together by GFRP wrapping layers, are used to restrict core steel component buckling instead of conventional steel tube and infilled concrete or mortar. Although the afore-mentioned studies have been conducted, there is still a long way to apply the ABRBs in practical engineering since the configurations and fabrication are commonly complicated. Moreover, the outer restraining members of the welding-ABRBs will be destroyed when replacing the core plate element. For the bolting-ABRBs, the fabrication precision and cost is generally high and thus unattractive for civil engineers.

This study aims to propose a new ABRB without using traditional welding or bolting method for assembling subassemblies. As shown in Fig. 1, the new ABRB is composed of three components, i.e., the core plate element, a pair of concrete infilled channel steel, and the wrapped carbon or basalt fiber cloth. The pair of concrete infilled channel steel sandwiches the core plate element and serves as a restraining member. The wrapped carbon or basalt fiber cloth provides the constraints for subassembly connection. Since the carbon or basalt fiber is a cheap and high-strength material, the fiber cloth can significantly reduce the fabrication cost of the ABRB. Meanwhile, the fiber cloth can provide sufficient constraints to prevent the separation of a pair of restraining members and resist the lateral thrust at restraining members exerted by the core plate after its buckling. Compared to the ABRBs assembled by welding or bolts, the presented ABRB is easier to be disassembled by cutting the wrapped fiber cloth. Moreover, the fiber cloth can greatly improve the corrosion resistance of outer steel tube. This is valuable to ensure the durability of the ABRBs even when they are subjected to a hostile environment. A total of eight specimens are designed and tested to examine the mechanical property, hysteretic behavior and energy absorption capacity of the presented ABRB with considering different loading protocols and different constraint ratios. Besides, nonlinear finite element analyses are also conducted for the specimens.



(b) The interface pressure between the core plate and concrete

Fig. 2. Forces acting on restraining members against multi-mode buckling.

2. Design requirements of ABRBs

2.1. Global flexural buckling

The global flexural buckling load P_e of BRB specimen is calculated by the following expression:

$$P_e = \frac{\pi^2(0.05E_1I_1 + E_rI_r)}{L_t^2} \quad (1)$$