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A novel brace with partial buckling restraint: An experimental and numerical investigation

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ABSTRACT

For the immediate damage evaluation of a buckling-restrained brace (BRB) after earthquakes, a novel brace with partial buckling restraint was proposed. In the novel brace called the partially buckling-restrained brace (PBRB), only the edge parts of the core member are restrained, and the middle portion of the core member, the unrestrained part, is designed for visual inspection. This paper focuses on the partial restraining mechanism of the PBRB, and three PBRB specimens were tested and compared with two conventional BRB specimens. The unrestrained ratio of the width of the unrestrained part to the thickness of the same part was studied as one of the key parameters that affects the behaviour of the PBRB. Even if the PBRB shows relatively lower fatigue properties and higher compression strength adjustment factors compared with the conventional BRB, the behaviour of the PBRB is still acceptable. The PBRB with a large unrestrained ratio fails at the end of the yielding core plate, where the unrestrained buckling deformation of the core plate is significant, but the fracture of the PBRB with a small unrestrained ratio occurs around the stopper, similar to the failure mode of the BRB. Numerical results show that the maximum plastic strain concentrates in the wave valley of the ends of the yielding core plate for the PBRB with the large unrestrained ratio. To make sure that the behaviour of the PBRB is comparable to that of the conventional BRB, it is recommended that the unrestrained ratio should be less than 5.

1. Introduction

One of the major challenges for civil engineering is to better design structures to withstand the destructive effects of earthquakes and strong winds. To improve the seismic behaviour of structures, innovative concepts of passive control have been widely used in the past decades [1], including metallic systems, viscous and viscoelastic systems, dynamic vibration absorber systems, friction systems, etc. These passive control systems dissipate damaging energy or counteract damaging force on the structure, so the main part of the structure, columns or beams almost remains elastic during a seismic event. With superior stable behaviour and long-term reliability, metallic systems take advantage of the hysteretic behaviours of metals when deformed into their plastic range.

As one of the metallic systems, the Buckling-Restrained Brace (BRB) has been found used for increasingly widespread applications in Japan, US, Taiwan and elsewhere [2,3]. The BRB is a particular type of brace with an overall buckling restrained by suitable equipment. The avoidance of global buckling means that the compression force-displacement behaviour is very similar to the response displayed under tension forces. Many researchers have conducted experimental or numerical studies of the BRB both at component and frame levels [4–10].

As shown in Fig. 1(a) [11,12], both pouring and curing the concrete or mortar in the BRB with concrete-filled tubes are time expensive. Local buckling is prone to occur because of the crush of the concrete or mortar [13]. To overcome these disadvantages, all-steel BRBs have been studied by researchers [14–19]. Since the density of steel is relatively high, about triple of the density of concrete, the solid section as the BRBs with concrete-filled tubes (Fig. 1(a)) is not applicable for all-steel BRBs for the sake of being lightweight. In fact, all-steel BRBs with solid sections (Fig. 1(b)) were employed only to investigate the basic properties of BRBs [20] since they are easy to fabricate and assemble.

2. Proposed devices

2.1. New concept of the BRB for inspection

There may be strong aftershocks following the main quake. To guarantee effective seismic behaviour of the BRB frames (BRBFs),

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Notation

b	width of yielding core plate	d	out-of-plane gap width between core member and restraining members
t	thickness of yielding core plate	L_t	total length of core member
b_u	unrestrained portion's width of yielding core plate	L_y	length of yielding core plate
b_0	width of outer plate	E	elastic Young's modulus
t_0	thickness of outer plate	σ_y	yielding strength
b_i	width of partial restraining plate	ε_y	yielding strain
t_i	thickness of partial restraining plate	σ_u	ultimate tensile strength
b_f	width of filler	ε_u	ultimate tensile strain
t_f	thickness of filler	ζ_{eq}	equivalent viscous damping
d_0	in-plane gap width between core member and restraining members		

(a) BRB with concrete-filled tubes (b) all-steel BRB for research

Fig. 1. Two conventional BRB sections.

which might experience multiple earthquakes and aftershocks within their service life, the development of a technique for inspecting the BRB is necessary [21]. Although previous researchers have proposed BRBs, which could be disassembled for inspection of the core member after earthquakes [20,22,23], it is rather difficult to reassemble the restraining members and the core member due to large plastic deformations. Therefore, it would be beneficial if the core member could be visually inspected without disassembling the BRBs after earthquakes. For example, a new configuration of the BRB, composed of a steel core plate and two identical restraining members that restrain the core plate by bolts at a specific spacing, is proposed, and the core member can be immediately inspected through the space between the bolts without disassembling the BRB after earthquakes [21].

Another new type of BRB with advantage of immediate inspection without disassembling is demonstrated in Fig. 2. As shown in the A-A cross-section in Fig. 2(b), the edge parts of the core member are restrained by four tubes. In addition, to integrate the two restraining tubes at each side of the core member, the collectors are equidistantly welded along the longitudinal direction of the brace between the two tubes. Thus, the core member can be conveniently inspected directly through the space between the collectors. In this paper, the brace with a partial buckling restraint is called the partially buckling-restrained brace (PBRB).

When compared with the conventional BRB whose core member is completely restrained by tubes shown in Fig. 2(c), the configuration of the restraining member of the PBRB results in the same cross-sectional moment of inertia with a smaller total cross-sectional area of the restraining tubes.

2.2. Configuration and dimensions of specimens

Since the restraining mechanism of PBRBs is different from that of conventional BRBs, the first step is to check the validity of the partial buckling restraining mechanism and to study the buckling behaviour and low-cycle fatigue properties of the PBRBs.

For experimental convenience, as shown in Fig. 3, the simplified configuration of the PBRB is employed in the experiments. The steel PBRB is made up of a core member, two pairs of inner partially restraining plates, two filler plates and two outer plates, as shown in Fig. 3(b). The core member is placed between two outer plates and four inner partially restraining plates that are assembled by high-strength bolts, pre-tensioned to 120 N·m, through two fillers. A 1-mm thick butyl sealant layer is employed as the unbonding material between the core member and the partially restraining plates or the fillers.

As shown in Fig. 4, the core member consists of a yielding core plate, two transition segments and two end projections with welded ribs. In the middle of the yielding core plate, the stopper is designed by enlarging the core member's width to prevent the outer plates from slipping off. The core member, except for the ribs, is directly wire electrode cut from a plain plate, and the ribs are welded to the core member by fillet welds. As presented in Table 1, all tested specimens are divided into two series with different core member geometric dimensions and material properties; its nominal width b is 100 mm in series I (specimens BRB-1 and PBRB-1), and 80 mm in series II (specimens BRB-2, PBRB-2 and PBRB-3). Table 1 also lists measured geometrical dimensions of the partially restraining plates. The main difference between the PBRB specimens in each series is the inner partially restraining plate's width

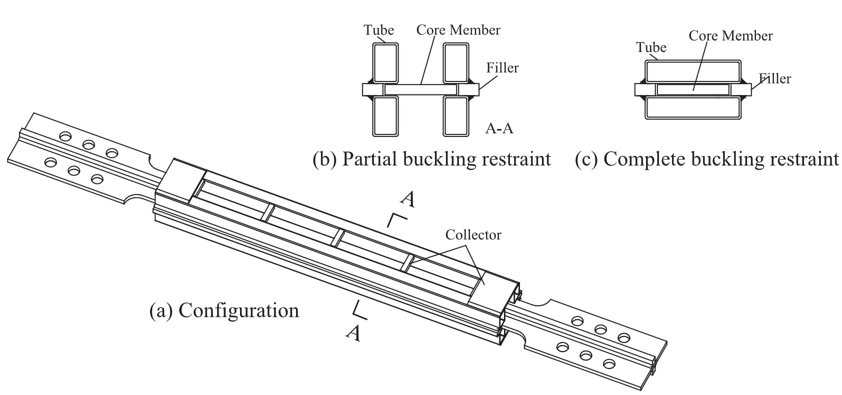

Fig. 2. Braces with different buckling restraints.