Experimental investigation on new configurations of Naturally Buckling Braces (NBBs)

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Introduction

The Naturally Buckling Brace (NBB) is a new type of steel brace developed by the writers, which consists of a high-strength (HS) and a low-yielding (LY) steel channel arranged in parallel with an intentional eccentricity, *e*, along the brace length (Fig. 1) (Hsiao et al. 2015). The NBB provides a ductile seismic behavior and stable dissipate energy without strength deterioration up to 4% story drift. It avoids deficiencies derived from conventional steel braces such as, no dissipation energy at small drifts, zero post-yielding stiffness and intense local buckling at the mid-length followed by fracture at nearly 2% drift. To make the construction of NBB feasible in practice, new configurations are proposed. The efficiency of the new configurations was evaluated by conducting cyclic quasi-static tests in three specimens. The test results showed that the proposed configurations kept the NBB's original characteristics, while all specimens experienced similar cyclic responses.

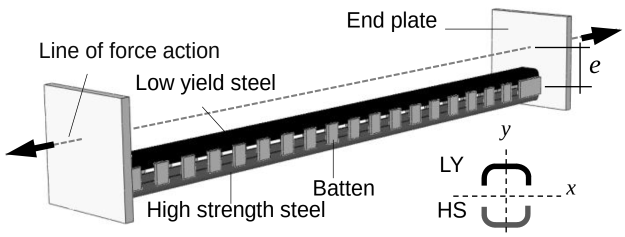

Fig. 1. Original NBB configuration

New NBB configuration

In the NBB concept, two channels of HS and LY steel are connected along the brace length to form a built-up compact cross-section and therefore, in deformed shape, the plain sections remain plains. For this reason, a conservative way had been adopted in the original NBB configuration (Hsiao et al. 2015), where a sufficient number of welded battens was used as shown in Fig. 1. This study explores a new section configuration using bolts avoiding the "multi-point" welding around each batten area (Fig. 2). To make the bolted connection much easier, the shape of channel is modified to a new channel shape with an extended part named 'wing' which is cold-formed by a press bending machine. The surfaces of wings are connected by four high strength bolts (two at each side).

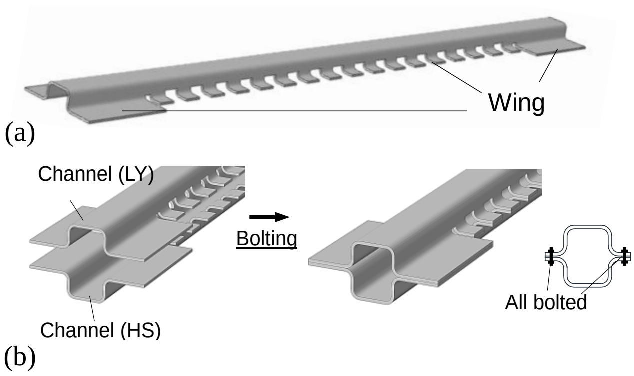

Fig. 2. New NBB design: (a) Channel with wing; (b) Connection of channels using bolts

Next, the application of gusset plates (GP) for accommodating intentional eccentricity is examined. The eccentricity *e* is applied through a T-shaped knife plate, as shown in Fig. 3, which is inserted to the brace ends through slots and is welded to the NBB. Then, the T-shaped knife plate is bolted to the GP which has 9 mm thickness designed according to AISC (2005) recommendations. The GP is also designed to have distance clearance equal to three times of its thickness (Fig. 3). This distance ensures enough width for developing of the plastic rotations caused by the out-of-plane rotation of the brace.

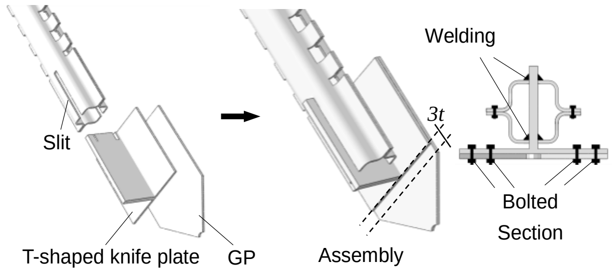

Fig. 3. Connection of NBB

Test specimens

To examine the new NBB configurations, three specimens were tested for quasi-static cyclic loading. The test parameters were the section configuration (Batten or Wing) and the type of support (GP or Mechanical pin). The letters in specimen name in the following test results indicate section configuration (B for batten, W for wing), and support type (G for gusset plate, P for mechanical pin). The NBB specimens were installed into a pinned frame with 45° angle and subjected to a cyclic loading protocol with increasing amplitudes from 0.1 to 4.0% story drift. The cross-sections had 114 mm total height, 93 mm width and 6 mm thickness. The pin-to-pin length was 2,132 mm and the applied eccentricity *e* was 80 mm.

Experimental Results

Fig. 4 compares the hysteresis loops of the specimens. The specimen with GP (W-G) reached 10% larger compressive strength and had 8% larger initial stiffness K_e compared with the pin connected specimen (W-P), while no significant influence was observed in the maximum tensile strength (Fig. 4(a)). Compared to the specimen with bolted wings (W-G), the specimen with welded battens (B-G) appeared slightly higher initial stiffness (5%) and maximum tensile strength (10%), and slightly smaller compressive strength (Fig. 4(b)).

Fig 5 depicts the progress of local buckling for the specimens B-G and W-G at 4% story drift. In the former, the battens acted as restrainers keeping the damage in lower level than the latter, in which the wings were completely deformed making the damage more intense and severe. For this reason, the specimens reached different strengths at the high drift levels, as shown in Fig. 4(b).

The above comparisons showed negligible differences between the original and the new NBB configurations. Therefore, the proposed configuration with the wing-shaped bolted cross-section and gusset plate connections can be adopted in practice.

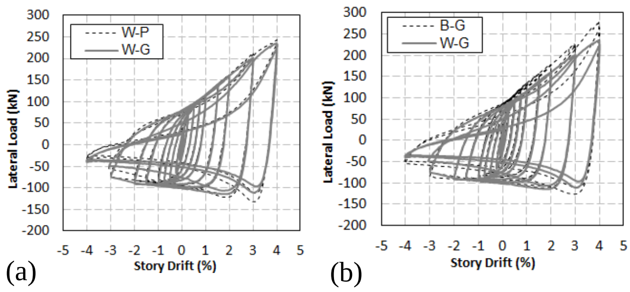

Fig. 4 (a) GP vs mechanical pin; and (b) welded batten-section vs bolted wing-section

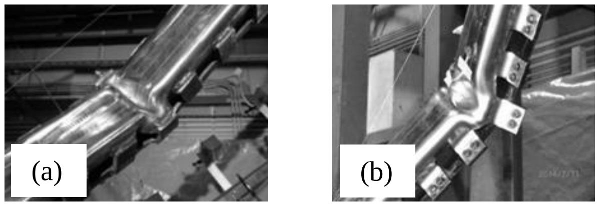

Fig. 5 Local buckling at 4% story drift: (a) B-G; and (b) W-G

Conclusions

The new NBB configuration intended for practical usage enjoyed the same seismic performance benefited by the original NBB design, such as early damping, large post-yielding stiffness and high ductility. The test results showed the efficiency: a) to adopt gusset plate instead of mechanical pin; b) of the bolted built-up cross-section instead of welded one; and c) of the introduction eccentricity by T-shaped knife plate.

References

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