Steel Braces with Intentional Eccentricity Treated by Induction Hardening

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Introduction

Conventional steel braces, after yielding in tension, provide with very limited post-yielding stiffness. The sudden loss of stiffness often related to the soft-story failure mechanism in steel buildings. Moreover, intense local buckling of brace mid-length occurs which leads to unstable energy dissipation, and finally to early fracture [1]. The ductility of the braced structure decreases. To overcome these deficiencies, the present study proposes a prototype design of steel braces. An intentional eccentricity applies along the length of the member (Brace with intentional eccentricity – BIE) [2] combined with a significant cross-sectional strength variation achieved by using induction heating (IH) and quenching process. The new design increases the post-yielding stiffness in tension and delays the occurrence of local buckling in compression. This study introduces the basic concept and experimental results of the proposed brace.

Steel brace concept

The IH process is very efficient non-contact way to heat up only a selected area of steel members. Fig. 1(a) shows the process. A coil heats up the half section of the steel tube over 1000ºC. Then, by cooling the heated steel surface rapidly with water (quenching), the workpiece obtains two-to-three times larger yielding stress than conventional steel (CS), as shown in Fig. 1(b). As a result, a significant strength variation is achieved within the same steel section. However, IH steel exhibited almost three times lower fracture ductility than CS based on a series of coupon tests (Fig. 1(b)), and this feature should be considered in the brace design. This study proposes an IH-treated circular hollow tube for steel braces, where its half cross-section has 2.6 higher strength than the other one (Fig. 1(c)). The dual action of cross-sectional strength variation and eccentricity realizes unique design properties in the proposed brace

Experimental investigation

A STK400 circular HSS tube with D/t = 32.7 and slenderness ratio λ = 54 (brace length 2,131 mm) is tested under cyclic loading. The clear length of the steel tubes was 1,575 mm. An eccentricity equal to 60 mm was adopted. The lateral loading history consisted of several drift levels (0.1~4.0%) with two cycles imposed at each level. Fig. 2 compares test results of an IH-BIE

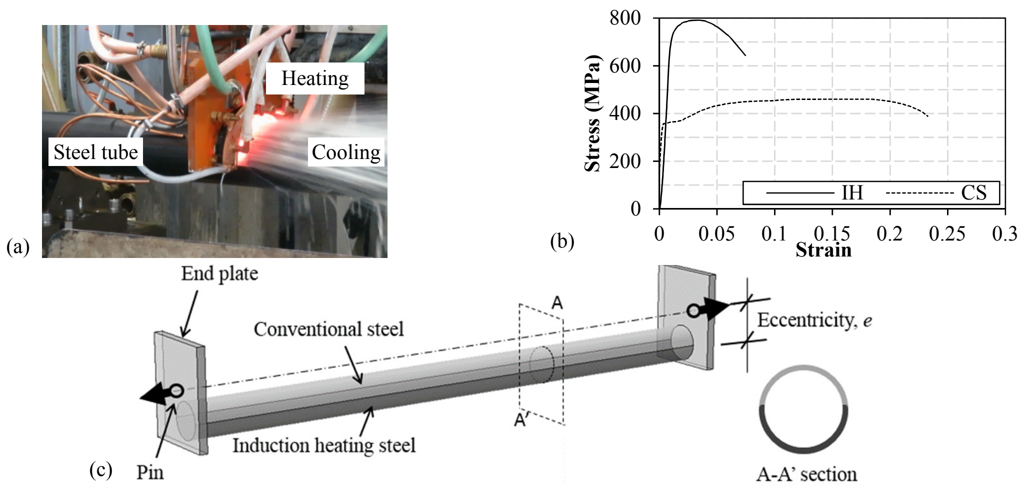

Fig. 1 (a) Induction heating and quenching process; (b) stress-strain relationship; (c) proposed steel brace

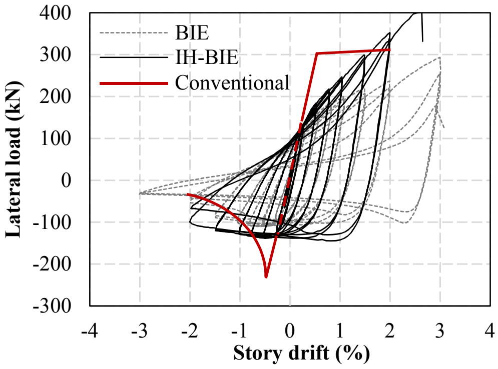

Fig. 2 Hysteretic behavior of IH-BIE and BIE

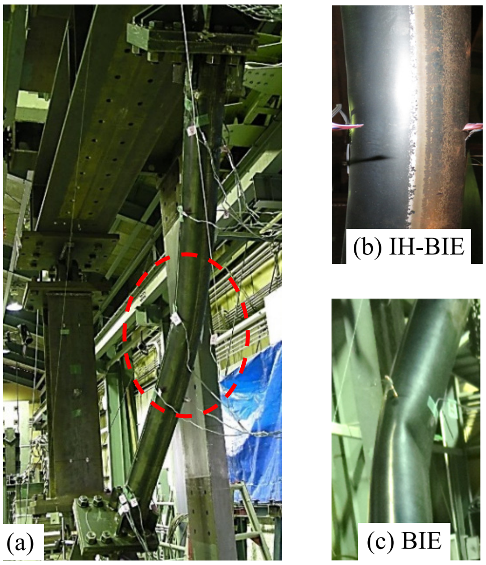

Fig.3 (a) Overall deformation of IH-BIE in compression; (b) local buckling delay in IH-BIE; (c) local buckling in

with a corresponding conventional BIE (no IH-treatment). The backbone of a corresponding conventional brace (no IH and w/o eccentricity) is also illustrated. The test results of IH-BIE showed that IH section remained elastic until 1.5% story drift while conventional steel section started yielding at 0.2% story drift. Due to the earlier yielding, the proposed brace provided large post-yielding stiffness, about 20% of the initial stiffness. This post-yielding stiffness was 1.8 times larger than that of a conventional BIE. In compression, the proposed brace smoothly shifted to post buckling behavior without significant reduction of compressive strength. After that, the reduction of compressive strength was smaller than 20% of maximum compressive strength until local buckling happened at second cycle of 2.0% story drift level.

Fig. 3(a) depicts the overall deformation of the IH-BIE in compression. Fig. 3(b) and (c) show photographs with the deformation of the IH-BIE and BIE at the mid-length, respectively. Local buckling occurred in BIE at first compressive cycle of 2.0%, while no local buckling occurred at that time in IH-BIE.

Discussion

The eccentricity naturally affects the brace behavior. Under tension, a trilinear behavior is observed, while in compression the brace does not reach the compressive load of conventional braces (Fig 2). The reduced strength capacity by the eccentricity recovers to some extent by applying IH and the strength per weight of brace increases. In addition, IH steel part remains elastic and undamaged until very large axial deformations providing thus high stiffness beyond the yielding of the conventional steel part. The post-yielding stiffness appreciably enhances. Finally, the inherent moment combined with the elastic behavior of IH steel part distribute stresses and strains more uniformly along the brace length. The occurrence of local buckling in the middle delays further in IH-BIE. A stable energy dissipative capacity up to very large axial deformation is provided.

Conclusions

The following conclusions are drawn:

a) IH steel provides with two-to-three times higher yield stress and ultimate strength than the conventional steel. The fracture ductility reduces about three times.

b) The IH-brace exhibited a large tensile post-yielding stiffness equal to 20% of the initial stiffness and an improved local-buckling ductility. Local buckling occurred in the second cycle of a 2.0% story drift.

References

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[2] K. A. Skalomenos, H. Inamasu, H. Shimada, M. Nakashima, Development of a Steel Brace with Intentional Eccentricity and Experimental Validation. Journal of Structural Engineering, 143(8), 04017072, 2017.