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Conceptual numerical investigation of all-steel Tube-in-Tube buckling restrained braces

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ABSTRACT

Introducing the concept of Tube-in-Tube buckling restrained brace (TiTBRB) members, a comprehensive parametric investigation has been carried out involving the influential parameters affecting the behaviour and modes of failure of the TiTBRBs during cyclic loading through detailed finite element analysis procedures accounting for material and geometric nonlinearities as well as the effects of gaps and contacts.

Several BRB related parameters have been considered here for parametric analysis that had not been investigated previously: the strength and stiffness of external restraining tube, the core strength, the core diameter to thickness ratio, the friction coefficient between the core and the restraining tube, the gap size between the core and the external tube, the gap size between rings and the external tube, the magnitude of initial imperfection, the number of intermediate rings along the length of the member and the particulars of the end collars.

On the basis of the finite element analyses results, it has been demonstrated that the proposed TiTBRB - if well designed - would be quite competent in accomplishing the intended tasks as a buckling restrained bracing member. Properly designed TiTBRBs can exhibit stable cyclic behaviour and satisfactory cumulative plastic ductility capacity, so that they can serve as effective hysteretic dampers. At the same time, in such all-steel TiTBRBs concreting has been eliminated and hence much lighter members are obtained. This is also associated with ease and speed of fabrication, erection, inspection, replacement and hence a more economical and environmentally friendly design.

1. Introduction

Buckling Restrained Brace (BRB) is a catch-all term which refers to any structural component that exhibits balanced and approximately symmetric, repeatable hysteretic behaviour by restricting buckling under reversal cyclic loading. Acting as a potential yielding metallic damper, BRBs absorb substantial amount of the seismic energy through stable cyclic yielding of the steel core which makes BRBs robust options for a diversity of applications in seismic regions.

During the past decades a number of experimental and analytical studies have been conducted for the development of conventional concrete filled BRBs (e.g. [1–4].) and to introduce a unified design procedure for the seismic design of steel buckling-restrained braced frames (BRBFs) (e.g. [5–7].). Specially, design recommendations have been incorporated into AISC Seismic Provisions for Structural Steel Buildings [8]. Considerable attention has been payed to traditional all-steel BRBs with core plates (e.g. [9–12].). In the latter type of BRBs, similar to concrete filled BRBs, the core member is made up of steel plate restrained by steel elements and connectors. However, despite potential advantages of Tube-in-Tube BRB (TiTBRB) systems, research works on such members have been very limited and hence further studies are needed before a comprehensive design guidance can be provided.

In an all-steel Tube-in-Tube BRB, the steel core and external restraining member are made up of Circular Hollow Sections (CHSs) without infilled concrete or mortar. Intermediate rings are used to make it possible for the external tube to act as the restrainer to prevent buckling of the interior core tube. Thus there is no need for the application of unbonding materials on the steel core. In this manner, the fabrication steps associated with applying the unbonding materials, pouring and curing the concrete or mortar are excluded that considerably reduces manufacturing costs and time. In addition, the lighter weight of such all-steel BRBs-compared with the ones with infilled concrete-are associated with ease and speed of fabrication, transportation, erection, inspection, disassembly and replacement.

1.1. The idea of the use of Tube-in-Tube sections as BRB members

The idea of the use of tube-in-tube members with intermediate rings as buckling restrained braces was developed as a result of observations

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made by Maalek [13] during experimental works carried out on double Circular Hollow Sections (CHS) - one located inside the other - for a quite different purpose. The setup used for those tests is shown in Fig. 1a. As described in detail in [13,14], during the construction of an air-craft hangar, tests had been performed on double CHSs to explore the potentiality of the use of a tube-in-tube section instead of a larger size single section which was not manufactured at the time by Iranian tube manufacturers. Hence, two series of tube-in-tube members had been constructed and tested: the members in which there was no intermediate connection between tubes along their lengths, as suggested by the project contractor, and the specimens in which intermediate rings had been employed to provide transverse load transmission between the inner tubes and the external ones. The rings had been employed at intervals along the inner tube length with a proper thickness, welded by spot welding to the inner tube, in order to provide just a minimum clearance to let the passage of the outer tube (See Fig. 1b and c). In this manner, it was expected that with the initiation of buckling in either of the tubes followed by a small lateral deflection, the two tubes would come into contact and act together. Fig. 1d shows the buckled double tube member without intermediate rings, which has been cut to show that there has been no initial contact between the two tubes along the length of the member. A comparison of the experimental results for double tubes, without and with an intermediate ring at the mid-length is given in Fig. 1e. As shown in the figure, the ultimate load of the tube-in-tube member acting together through the intermediate ring, was 1.75 times the maximum load of the member without such a filler ring.

The above observations led to the development of the idea of the use of tube-in-tube elements, as BRB members. However, in the case of tube-in-tube BRB which is considered in the present study, the role of the outer tube is to prevent buckling of the inner one which is intended to act as the structural core of a BRB member during cyclic loading.

1.2. Pertinent previous researches

Ghasemi [15] and Maalek and Ghasemi [14] introduced BRB members composed of double circular hollow sections, one located inside the other, referred to as Double Circular Hollow Section BRB (DCHS-BRB). Through a series of detailed finite element analyses calibrated by laboratory test results, it was demonstrated that the introduced double-tube/tube-in-tube member was capable of achieving the intended tasks as a buckling restrained bracing member. Moreover, with the consideration of various aspects of particular interest such as the construction costs, ease and speed of fabrication and erection, it was shown that the proposed Tube-in-Tube buckling restrained member introduces some advantages over the BRBs in which a core has been surrounded by RHS tubular sleeves in-filled by concrete [15].

The cyclic and monotonic behaviour of the introduced Tube-in-Tube BRB members was further investigated by Omidi [16]. Two specimens with different lengths (i.e. 3 m and 6 m) were considered and investigated numerically through a series of finite element analyses. Based on the results, it was shown that the proposed Tube-in-Tube BRB had a good hysteretic performance under cyclic loading. Fotoohabadi [17] extended the previous investigations towards the application of Tube-in-Tube BRBs in actual steel frames to compare the seismic performance of special concentrically braced frames (SCBFs) and frames equipped with the TiTBRBs. A full-scale 5–story building was designed based on the AISC specifications and seismic provisions considering both the SCBF system as well as the proposed BRBF. Three scaled ground motion records were used to conduct the nonlinear dynamic analysis to compare seismic response of the building structure under consideration. The static push over analyses were also performed for further comparison of SCBF and BRBF performance under monotonically increasing loading under displacement control. On the basis of results, the seismic performance of the prototype framed structures equipped with TiTBRB was superior to the SCBF system.

Later to the above works, the present authors, during their current study, learned about the works of Yin et al. [18], Yin and Wang [19,20] and Yin and Bu [21] published recently, well after the works reported in [14,15]. In this series of research, the performance of double steel-tube BRBs has been studied through numerical simulation and small scale experimental tests. It has been reported that the double-tube BRB with contact rings prevented the buckling of the core member to enable yielding under both compression and tension. It has just been noted that the number of the contact rings, the stiffness of the restraining tube and the clearance between the tubes influence the hysteretic behaviour of the BRBs under consideration [20].

In another research, Zhang et al. [22] have proposed a BRB system using three concentric circular steel tubes in which the slotted middle tube has been considered to act as the yielding core and the outer and inner tubes restrain the out-of-plane deformation of the core tube. The number and size of slotted holes on the core tube have been considered as the main test parameters. Accordingly, five specimens have been considered with welded fixed end boundary conditions and

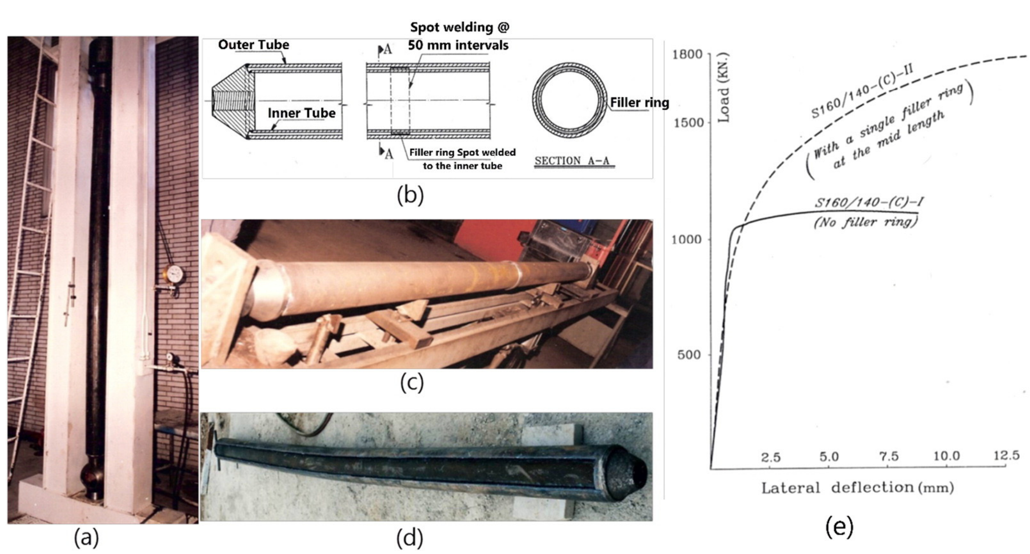

Fig. 1. a) Test setup, b) The proposed tube-in-tube member consisting of double CHS tubes with intermediate filler ring(s) to replace the unavailable single tube section, c) The installation of the intermediate ring on the internal tube, d) Buckled tube-in-tube member without intermediate ring cut along the length of the outer tube, e) Load - lateral deflection relationship for tube-in-tube members with and without a contact ring at the mid-length (after Maalek [13]).