# Buckling Restrained Braces (BRB) in framed structures as Structural Fuses in Seismic Regions – A Review

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**Abstract -** *The moment-resisting frames are susceptible to large lateral displacements during severe earthquakes. In order to limit inter storey displacements, special attention is required in design so that potential problems due to geometric non-linearities and brittle or ductile fracture of beam-to-column connections are mitigated and excessive damage to non-structural elements is avoided. With this concern, seismic design requirements for braced frames changed considerably during the 1990s, and the concept of special concentric braced frames called the Buckling Restrained Bracing (BRB) system were introduced. This paper presents a variety of results from the experimental studies made worldwide on BRBs as a 'damage protection alternative' to the structures during an earthquake. The inelastic cyclic behaviour of several types of buckling-restrained braces has been reported by detailed experimental investigation and analytical studies by scholars around the world. These tests typically resulted in hysteretic loops having nearly ideal bilinear hysteretic shapes, with moderate kinematic and isotropic hardening effect. Thus, it is evident that the BRBs are efficient structural fuses that can be incorporated in a structure to enhance its performance.*

***Key words:*** BRB, BRM, Bracings, Dampers, Hysteretic analysis, Earthquake

## INTRODUCTION

Buckling restrained braced frames (BRBFs) for seismic load resistance have been widely used in high seismic regions in the recent years. BRBs or buckling restrained braces are *structural dampers* proposed in seismic resistance design of structures. They comprise of two components: A steel core and a Buckling Restrained Mechanism (BRM) as shown in figure 1. The steel core is laterally restrained by BRM which is a steel tube filled with cement mortar or concrete or air gap with an unbonded material between the two. The core can yield in both compressions as well as in tension, which results in comparable yield resistance and ductility thus exhibiting a stable hysteric behaviour accompanied by enhanced ductility during earthquakes.


***Figure 1. Buckling Restrained Bracing***

The steel core after large quakes can be removed and replaced. Thus, they act as structural fuses that undergo damage during ground motions and offer protection to other structural elements. The mechanism of buckling restrained braces is shown in figure 2.

The Conventional bracing system introduced a few decades back, comprises of a central core encased in a steel tube filled with cement mortar. The heavy weight of these systems and the difficulty in curing and handling resulted in a new type BRBs called all-steel BRBs. The same mechanism is witnessed here but the unbounding agent is not necessary in this type thus making it lighter, easier and practicable to fabricate and handle, than the conventional BRBs. Also, all-steel BRBs can be easily dismantled and inspected after an earthquake. The previously proposed restraining member was a mortar-filled steel section, which made an extremely rigid member.

In such types of BRBs overall buckling was avoided by integrating the brace member and the BRM. However, in BRBs which are all-steel, the brace member is completely made of steel, and the BRM system is lighter than the conventional BRBs, which leads to a high possibility for brace overall buckling caused due to low rigidity and stiffness of the BRM. During axial deformation, the BRM should have enough strength and rigidity to prevent overall buckling of the brace. Therefore, to obtain the hysteretic characteristic on the compression side similar to that on the tension side and to mitigate pinching, it becomes necessary to avoid overall buckling (i.e., flexural buckling).

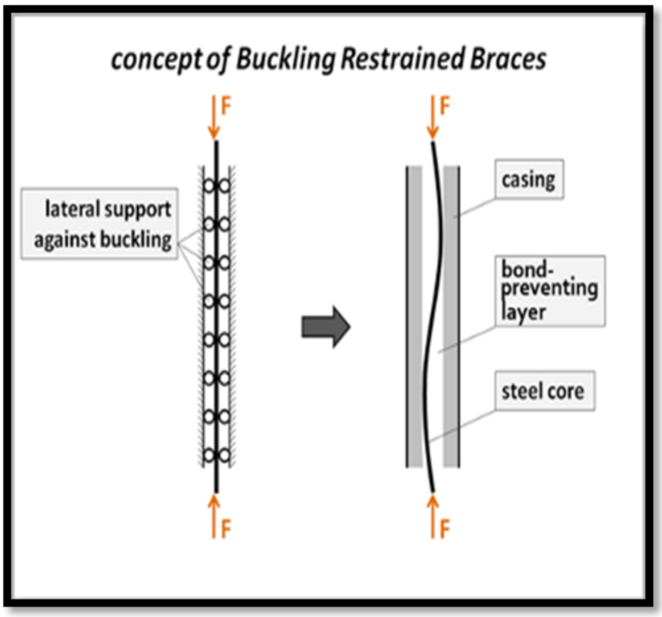


*Figure 2. Mechanism of BRBs*

The results of the first studies on overall buckling behaviour of BRBs conducted by Watanabe et al. (1988) found that the ratio of Euler buckling load of the restraining member to the yield strength of the core, is the factor that is the most responsible for control of brace global buckling. It was concluded that the brace member will experience overall buckling during cyclic loading of the braced frame if the ratio of the Euler buckling load of the BRM to the yield load of the inner core is less than 1.

## LITERATURE SURVEY

The difference between the tensile and compression capacity of the brace, and the degradation of brace capacity under compressive and cyclic loading, led the way to the development of braces which exhibit more ideal elasto-plastic behaviour. This ideal behaviour was obtained through metallic yielding, where buckling in compression is restrained by an external mechanism called the buckling restrained mechanism.

A wide area of researches has been made to accomplish this and suggested that a ductile metal (usually steel) core (rectangular or cruciform plates, circular rods, etc.) encased in a concrete filled steel tube which is continuous, within a continuous steel tube, a steel tube with intermittent stiffening fins, and so on. The assembly works such that the central yielding core can deform longitudinally independent from the mechanism that restrains lateral and local buckling. Large inelastic capacities are obtained if lateral and local buckling behaviour modes are restrained. The inelastic cyclic behaviour of several types of buckling-restrained braces has been reported by detailed experimental investigation and analytical studies. These tests typically resulted in hysteretic loops having nearly ideal bilinear hysteretic shapes, with moderate kinematic and isotropic hardening evident. The efficacy of buckling restrained braces thus becomes valid from the literatures discussed below:

Watanabe et al. (1988) proved that when the buckling restrained braces are incorporated in a frame and the ends are subjected to the effects of bending moment, buckling of the whole member does not take place if Euler load of the steel tube is greater than the yield strength of the core member.

Tremblay et. al. (2004) conducted a quasi-static load test on BRB and showed that the strain hardening behaviour is most likely the result of the Poisson effect on the steel plate undergoing large inelastic deformation.

L.DiSarno and G.Manfredi (2010) performed comprehensive nonlinear static and dynamic analyses for an as-built and structures retrofitted with BRBs and found that the braced frame experienced higher period of elongation than bare frame and concluded that BRBs are effective to enhance ductility and energy dissipation of the sample structural system

Stephen Mahin et al. investigated three buckling-restrained braced frames and concluded that the subassembly tests conducted validated BRBs as an effective seismic lateral system and can be used for large energy dissipation capacity.

Sh.Hosseinzadeh and B.Mohebi (2015) assessed the non- linear static and dynamic responses of all steel buckling restrained braces and suggested they could be used to retrofit 4, 8 and 12 storey frames with immediate occupancy performance level and the axial forces imposed on the first story columns of the retrofitted structure witnessed a maximum reduction of 18% compared to the non- retrofitted counterpart.

N.Hoveidae and B Rafezy (2012) conducted a parametric study of BRBs with different amounts of gap between the core and the BRM and initial imperfections to investigate the global buckling behaviour of the brace. The results of the analysis showed that the mechanism of buckling restrained flexural stiffness could significantly affect the global buckling behaviour of a brace, irrespective of the size of the gap.

N.Hoveidae and B Rafezy also performed finite element analyses of all-steel BRBs to investigate the effect of the interface detail on local buckling behaviour of the brace member and the effect of the magnitude of friction coefficient of the contact between the core and the BRM and concluded that increase in frictional response and the compression strength adjustment factor is due to the increase in the magnitude of friction coefficient of the core and the BRM contact.

G.Plazzo et al. (2009) investigated simple, low maintenance, patent free, dissipative buckling restrained braces to study the cyclic axial deformation until failure and the tests showed that the devices performed properly without relevant shear stress transfer to the casing added to a stable hysteretic behaviour, also the mortar remained undamaged due to the lateral pushing of the core due to local buckling.

Jinkoo Kim and Youngsil Seo (2004) validated the applicability of BRBs in low rise steel frames on conducting a performance based seismic design procedure for buckling restrained braced frames with pin connected beam column joints and evaluated that the maximum displacements of modelled structures corresponded well with the target displacements. Also, the BRBs dissipated most of the vibration energy through inelastic deformation while other structures remained inelastic and undamaged.

Jinkoo Kim and Hyunhoon Choi investigated the equivalent damping and performance of structures with BRB and found that the maximum displacements of structures generally decrease as the stiffness of BRB increases. Also, use of low strength steel for BRB, undergoes larger plastic deformation and dissipates more energy thus beneficial for reducing structural damage.

Black et al. (2002) conducted component testing of BRBs and studied the results of a hysteretic curve to compare the test results and found that the curve is stable, symmetrical, and ample. Young K Ju et al. analysed component tests of BRB and found that high energy dissipation capacity can be witnessed if the thickness of the external tube was sufficient and if unconstrained part of the core was properly reinforced.

Samer El Bahey and Michel Bruneau (2011) proved that the concept of BRBs as structural fuses for seismic retrofit of concrete bridge bents and proposed a design procedure validated by non-linear time history analyses presented.

Chun Che Chou and Shen Yang Chen (2010) conducted Sub-assemblage tests and finite element analyses of sandwiched buckling restrained braces and demonstrated that the cumulative plastic ductility was significantly larger than the minimum required plastic ductility specified in AISC seismic provisions.

Nikhil D. Sontakke and P. S. Lande (2016) made a comparative study and concluded that buckling restrained bracing can reduce the effect of lateral forces on a building compared to the conventional bracing systems. Qiang Xie (2005) investigated the use of BRBs for practical applications for buildings in Asia.

Clark et al. (1999) suggested a design procedure for buildings incorporating BRBs. Sabelli et. al (2003) reported seismic demands on BRBs through a seismic response analysis of BRB frames. Fahnestock et al. (2007) conducted a numerical analysis and pseudo dynamic experiments of large-scale BRB frames in the US. Local buckling behaviour of BRBs has been studied by Takeuchi et al. (2010). Similar experimental tests were conducted by Wei et al. (2008) to survey the local buckling behaviour of BRBs.

The effective buckling load of BRBs considering the stiffness of the end connection was recently studied by Tembata et al. (2004) and Kinoshita et al. (2007). In another experimental work, Ma et al. (2008) conducted experimental tests on six all-steel BRBs and studied the hysteretic behaviour of the braces. Subsequent numerical studies have been conducted by Korrzekwa et al. (2009) to investigate local buckling behaviour of the core plate in all-steel BRBs, which provided a description of the complex interaction that develops between the brace core and the BRM. It was found that the outward forces induced by the contact forces were found to be resisted in flexure by the BRM components. Moreover, the contact forces resulted in longitudinal frictional forces that induced axial compression loads in the BRM.

## METHODOLOGY

The experimental studies on BRBs gave the mode of failure, flexural and yield capacity of the BRBs. The moment revisiting frames even after large lateral loads remained untouched thus proves the performance of the buckling restrained braces. The Finite element analysis method is used to predict the buckling response of the core plate in BRBs and the modes of failure of both core and the restraining mechanism is studied. Assuming 1% imperfection in configuration cyclic analysis is done for the BRB model and their hysteretic behaviour and energy absorption capacity were analysed.

The results from Push over analysis, Response spectrum analysis and time history analysis detailed the complete behaviour of BRBs and the mechanism of damage protection. The conventional BRBs are in use in Japan and Taiwan.

## CONCLUSION

From previous research works it is concluded that the unbonded brace or the buckling restrained braces are reliable and practical alternatives to conventional framing systems to enhance earthquake resistance of structures satisfying structural drift limits while delivering a substantial energy absorption capacity.

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