A Study of the Behavior of Steel Moment Frame with Buckling Restrained Bracing (Review Article)

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<td>The use of bracing systems is one of the most suitable methods to control the lateral displacement of a structure as well as to improve the seismic rehabilitation of moment frames. The bracing systems used in the design of new systems and the rehabilitation of weak old structures are buckling restrained braces. In this study, the effect of this on the performance of steel moment frames is investigated. The use of buckling restrained braces has led to increased bracing stability and ductility under compression. Therefore, it creates a symmetry in the strength of the member under axial compressive and tensile load. For this reason, the full capacity of braces in tension and compression is used in the structural frame where braces are used double. Research results indicate that the first plastic hinging in a moment frame without a restrained buckling brace is formed in the base column and beam-to-column connection, which may lead to a crumbling failure.</td>
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1. Introduction

Moment frame system is one of the most widely used earthquake-resistant systems in the world. Due to its high ductility and elasticity, it is capable of displacement of structures and forces over the components' capacity in the structure, and the failure of structural and non-structural elements. Bracing system is a very suitable method to control the lateral displacement of the structure and the seismic rehabilitation of the moment frame. The new type of bracing systems used in designing new systems and rehabilitation of old weak structures is buckling restrained brace. In this study, its effect on steel moment frame is investigated.

A buckling restrained brace consists of a ductile steel core. This steel core is placed inside a rectangular or rounded section filled with concrete or mortar. Concrete or mortar that fills the round or square steel core causes delays in locally curved buckling. The section on the steel core is covered with a non-stick material to separate the concrete from the steel section. This non-stick material reduces the friction between steel and concrete as much as possible and reduces the transfer of axial force from the steel core to the concrete and the steel section of the shell, as the Poisson effect causes the core to expand under compression, a small gap between the core and the concrete is needed. Furthermore, in a compression area, conventional braces with hysteresis loops are unstable and energy absorption in the compression zone is low, whereas the braced braces against the buckling of the compression zone have stable hysteresis loops and the energy absorption in the compression area is equal to the tensile region. In fact, these kind of structural systems act like a hysteresis damper. Conventional concentric bracing systems have inherent difficulties in the difference in tensile and compressive behavior. These braces should be able to withstand large displacement of earthquake sites in axial direction and in stress strength after buckling. The buckling of the braces under compression reduces stiffness, strength and energy dissipation capacity.

Extreme weaknesses in ductility and low nonlinear seismicity have been shown in buckling behavior of braces under compression, with realistic measurements on SCBFs at the University of California, Berkeley, by Mr. Yuriz and colleagues. This deflection in concentric bracing structures (buckling braces under compression) has suggested the basic idea of
using buckling restrained bracing frames (BRBF). Buckling restrained bracing systems have been introduced to meet the design requirements and with regard to the economic benefits they bring about to the project. This system, by providing more ductile response and more energy absorption, as well as providing a sufficient strength and stiffness in large ductilities, are raised both in designing new structures and in improving the seismicity of existing structures - many of which exist in our country (buildings that have only resistant frames against gravity loads and do not have a lateral load system) and design options for new structures.

Buckling Restrained Bracing Frames (BRBFs) are a special type of braced frames that prevent the general buckling of the brace and reduce the strength and stiffness in them. The bracing elements have the ability to flow and provide equal behavior in stress and compression and, as a result, absorb energy in stable cycles. In Figure 1, the behavior of a buckling restrained element in a buckled cycle has been shown. The buckling of the element under compression has led to a sharp drop in strength and stiffness [1-2].

![Figure 1](image1.png)

**Figure 1.** The steady-state behavior of buckling restrained braces against buckled braces [1]

2. Buckling restrained brace

In Figure 2, a buckling restrained brace is shown against conventional buckling. It can be seen that this brace consists of three main parts.

![Figure 2](image2.png)

**Figure 2.** Different parts of buckling restrained brace [1]

- The steel core bearing the axial loads.
- Metal sheath and encasing concrete, which is responsible for preventing buckling of the core element.
- The separating agent that prevents the involvement of the encasing concrete and the core in the direction of the member's axis.

Each of these main parts, along with the following components, is described below:

2.1 Yielding steel core

This part is considered to be the main part of the brace that can withstand the axial load. Since the basic idea behind BRB braces is to yielding under compression, it is recommended that the core type is made of finely-less steel with lower strength to occur in reciprocating steel returns, and energy dissipation is well done. The research carried out by Mahin and Sabili (2003) [3] was designed to identify the behavioral characteristics of armed structures by buckling...
restrained braces, and in this regard, with the help of earlier research, the vibrational performance of buildings under the vibratory motion of the earth has also been identified. The main focus of this study was to investigate the vibrating performance of the three and six floor buildings with buckling restrained bracing frames. There is also a brief discussion of the mechanical properties of braces and the advantages of using them. Finally, the results of nonlinear dynamic analysis for different alternatives are presented to determine the effect of these parameters on the specifications and structural characteristics. A number of shapes used for the steel core section are given in Fig. 3, below.

In studies conducted by Uang and Kiggins (2006), [4-5], the highly desirable features of the use of systems with buckling restrained braces have been proven. It has been shown that the use of buckling restrained bracing frames significantly reduces structural vulnerability against large drifts. In this research, the advantages of using buckling braces in dual systems with minimizing permanent deformation are discussed. The results of time collapse analysis have shown that the use of dual systems reduces the deviation of floors in these types of structures. In a study by Kim and Choi (2006) [6], a vibrational energy-based design method for buckling restrained brace frames is proposed using hysteretic energy spectra and accumulated ductility spectra. This method is based on the assumption of the gravitational strength of the elements such as beams and columns, which should remain elastic during the earthquake, and all earthquake input energy should be dissipated by buckling restrained braces. Based on the results of the analyses carried out using this method, the main values for the upper floor displacement correspond well to the target function displacements. Also, there was a within floor uniform deviation at the height of the building, which has a good performance due to the uniform distribution of damage in height.

Shokrgozar and Asgarian [7] conducted a study entitled “Effect of Design Loads on Buckling Restrained Braced Frames Performance” in 2008. In this study, the strength, ductility and buckling restrained bracing frame modification factor were evaluated and calculated. For this purpose, buildings with different floors and different configurations for braces, such as the type of braces, diameters and angles are considered. Push over static analysis, incremental nonlinear dynamic analysis and linear dynamic analysis have been performed using Opensees software. The effects of some effective parameters on the response of the modification factor, including the height of the building and the type of bracing system, have been analyzed. Finally, in this research, the vibrating response of the modification factor for each of the braced systems was determined separately and the experimental values of 8.35 and 12 for the final limit state and the permitted stress design were proposed.

2.2 The unconfining steel core
In order to bind the brace to the building skeleton, part of the brace must inevitably be unconfining. In order for the buckling not to happen in the unconfining area, it should have a greater cross-section than the bounded part. The displacement of the section should not be sudden. This will result in stress concentration in the cross-sectional area. For this purpose, a transitional area is used. Through the transition region, the cross-sectional shape is mildly enlarged. This section is clearly visible in Fig. 4.

![Figure 3. Different forms of steel core and confining enclosure [1]](image-url)
In researches by Fahnestock and Wigle (2010) [8], nonlinear models using finite element method have been used to evaluate the behavior of buckling restrained frames at hinges. Extensive experimental studies have shown that although the use of buckling restrained braces improves the performance of structural frames against earthquake agglutination, the weak strength of such braces in the joints has limited this useful application. An analytical study has used a frame of a single floor.

In the next step, comparing numerical results with laboratory results, accuracy of modeling has been achieved. Then, by changing the details of the bracing member at the joint site, the effect of various parameters on the improvement of member function has been studied. The results show the desired results using new methods in the joint location.

In the research conducted by Yu Y.J. Et al (2011) [9], numerical models have been used to predict the dynamic responses of structures with buckling restrained braces. These numerical studies have been used before the laboratory tests to predict the behavior of buckling restrained bracing frames. A 3D finite element model has been used to investigate the strength of braces in the end joints. The results of dynamic tests on buckling restrained braces, together with the dampers connected to it, have also been evaluated. Based on numerical analyses and comparisons with the results of laboratory tests, nonlinear modeling techniques are recommended to investigate the behavior of buckling restrained bracing frames.

Almansa, Oller (2012) [10-17] investigated the cyclic behavior of a buckling restrained bracing member. In this research, the ductility and Connection Strength according to Fema450 and the finite element model of the sample (Girona Laboratory Model) were constructed running Abaqus software. Then, the curvatures of ductility and bracing strength on these curves were plotted and the cyclic behavior of the member was studied as a finite element.

Regarding the analysis and comparison of periodic analysis of buckling restrained braces for columns and beams, Chuo and Chi-Yu (2012) [18-19] changed the horizontal alignment of attachment screws with the finite element modeling of 10 samples running Abaqus software. According to the AISC-LRFD regulations, the results of the investigations for the same sections of the beam and column reflect the fact that slenderness ratio for this type of brace is equivalent to 2. Also, their research results showed that the distance between the bolts of the center of the beam connection to the buckling column is directly proportional.

### 2.3 Non-stick material

BRB mechanism is provided by this material. The non-stick material eliminates or minimizes the friction between the core and the confining concrete. According to this point, the non-stick material only transmits the lateral displacement of the core steel to the confining concrete and prevents the axial transmission to the confining concrete. Researchers have so far used different non-stick materials in their experiments. Rubber materials such as polyethylene, silicone oil and mastic oil are among the substances used as non-stick materials. There must be a suitable distance between the core steel and the confining concrete. This distance should not be so high that it allows the core steel to buckling in higher gears. In other words, the gap between the core and the concrete should be smaller than the buckling protrusion.

On the other hand, this gap should not be so small that the core steel be bonded to the confining concrete due to the expansion of the Poisson effect and enclose between the core and the friction concrete, which will transfer the axial force from the core to the confining concrete and consequently, the predicted mechanism will be eliminated. If there is a transitional section in the buckling brace, according to Figure 5, an empty space should be considered for expansion and contraction of the core. If this space is either small or not at all, then when stretching the core, the core will collide into concrete, and it will reduce the loading and unloading capacity of the buckling restrained brace, which in design based on the capacity is undesirable. This can also lead to unbalanced forces in the Chevron braces, while one of the advantages of buckling bracing is the elimination of this unbalanced force.
3. Comparison of all types of systems with the buckling bracing system

Chen and Chou (2009) presented an analytical study of the compressive strength of the central binding plate in frames with buckling restrained braces. In this research, the finite element method has been used and for this purpose a buckling restrained bracing frame model has been developed to predict buckling load on the central connection plate in the finite element software. The results were compared with the results of a laboratory study. Therefore, a parametric study has been made on the compressive strength of the interconnection plate with various dimensional characteristics. Finally, the buckling equation of the binding plate along with the proposed coefficient diagram was presented for predicting the final load.

Ou and Zhao (2012) studied and compared the periodic function of joint joints of buckling restrained braces with the beam and column and its impact on the lateral buckling of this kind of braces. He also conducted research on the shape of the metal core and the stiffness place. Hoveidae and Rafezy (2013) investigated and compared the analysis of the periodic function of buckling restrained braces and the buckling of the inner core. Their numerical research, carried out using the Abacus software, suggests Euler's extraction force for regulations.

Rahnavard et al. (2018) studied the numerical methods of buckling bracing modeling. They presented the method of using springs as an alternative method for modeling concrete and casing. The results were more accurate than complete modeling of concrete and casing. Naghavi et al. (2018) studied a variety of steel frame systems with two types of conventional bracing and buckling bracing. Their results showed that the moment frame with Chevron buckling brace has the best performance compared to all types of systems. The results also show that the moment frame of super-x braced frame is more efficient than other conventional systems.

Jea et al. (2014) developed a series of laboratory models to compare and analyze the periodicity analysis of steel moment frame system with buckling braces and moment frame without bracing. Their results showed that the moment frame with buckling restrained braces bears more than twice the shear force than the moment frame without bracing.

4. Conclusion

The results of this paper are summarized as follows:

- The use of buckling restrained brace has led to increased bracing stability and ductility under compression. Therefore, it creates a symmetry in the strength of the member under the tensile and compressive axial load, and therefore the full capacity of braces in tension and pressure is used in the system frame structure in which the braces are used double.
- The use of buckling restrained braces to improve the moment frame is appropriate because it prevents lateral ductility that is commonly the problems of moment frames.
- Due to the fact that the main task of the braces is to withstand lateral loads, the use of buckling restrained braces, in addition to increasing the safety of the structure, will make the rest of the structure slender, making the design more economical.
- The use of buckling restrained braces makes the structure of the frame function symmetrical, and therefore the performance of these structures will be improved against actual loads such as earthquakes that are reciprocating.
- The use of buckling restrained braces increases the energy dissipation to more than 4 times the moment frames.
- One of the features of moment frames with buckling restrained braces is that in the very large displacements, the frame in the beams is broken.
Using relationships, behavior coefficient for a moment frame with a buckling brace gives a number larger than 10. These numbers are slightly greater than the behavior coefficients of the frame with brace.

Research results have shown that the first plastic joint in the moment frame with buckling restrained braces, is located in the pivot of the binding plate.

Research results have also shown that the first plastic joint in the moment frame without buckling restrained braces is at the foot of the column and the connecting beam to the column, which may lead to a crumbling failure.

In most moment frame models with crosswise braces, it was shown that the plastic joint was usually formed in columns.

Proper reinforcement, relying on ease in executive issues, and also with regard to economic issues, this structural rehabilitation method provides a very good performance for strength, stiffness and ductility, which is one of the basic principles for an improvement plan.

5. References


