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A Review on Buckling Restrained Braces

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Abstract

One of the problems of common bracing system is their buckling against compressive loads, which reduces the amount of energy loss of the structure. Buckling Restrained Brace (BRB) have solved the problem of conventional braces by eliminating the overall buckling of the brace under pressure. Buckling Restrained Braced Frame (BRBF) is a new type of bracing system that has been widely used in recent years. Nowadays the use of buckling restrained braces, due to having more advantages compared to conventional steel braces, have received the attention of researchers and engineers that these advantages include: high ductility, more energy loss, no overall and local buckling, and also having a symmetrical cyclic curve. This type of bracing is considered as one of the effective systems for dealing with lateral loads caused by the earthquake. Disadvantages in the seismic behavior of conventional braces, such as ductility and low energy loss, general and local buckling, as well as having an asymmetric cyclic curve, have provided grounds for its modification or exclusion from the seismic design process. Buckling restrained braces are a type of energy loss system that, in addition to providing high lateral stiffness, increase the formability and energy loss of the structure. The use of this type of braces is allowed in the regulations of some countries. But in some other countries, including Iran, it has not been mentioned. According to the seismicity of the country and the increasing use of these structures in the world, the use and localization of this type of bracing system in Iran is inevitable, and the entry of this lateral bearing system into the design regulations, especially the earthquake regulations of Iran, is mandatory. The results of the analysis show that the energy loss capacity of the buckling restrained brace is about 5 times the energy loss capacity of the normal brace.
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Keywords: buckling restrained brace, hysteresis behavior, energy loss, cyclic load, resistance, passive control system;

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1. Introduction

The occurrence of an earthquake as a natural phenomenon in most regions of the world causes human casualties and structural and non-structural damages for various reasons. One of the main goals of earthquake engineering researchers is to reduce damages caused by earthquakes. Due to Iran's location on the Alpine-Himalaya earthquake belt, it is considered one of the earthquake-prone countries in the world, and based on previous experiences, the possibility of various earthquakes occurring is not far from expectation. Considering the damage caused by past earthquakes in Iran and the world on buildings, it is necessary to pay attention and use modern seismic systems in order to reduce the damage and increase the speed of the structure's return to its original state. Therefore, it is inevitable to use appropriate preparations in the lateral bearing systems of structures to reduce the damage caused by earthquakes. Today, it has been proven that the design of structures in such a way that they have fully elastic behavior to deal with severe earthquakes is not economical, as a result, methods such as passive control of structures against earthquakes are used in the design of structures. In this method, some structural members bear damages during severe earthquakes so that the damages on the main members of the structure such as columns are reduced and thus the structure is stay safe from major damages. Passive methods are generally divided into two categories: energy loss systems and base separators. bracing systems in steel frames are easier to implement and have a lower cost compared to bending frames; For this reason, they are widely used in steel buildings. However, with the occurrence of large and destructive earthquakes in the last few decades, many steel wind-braced buildings, which were designed according to the existing seismic design codes, did not show proper performance. Research has shown that many of the behavioral defects of conventional convergent braces are the result of the difference between compressive and tensile capacity and deterioration in the coaxial bracing system of these braces, which is caused by the buckling of the brace in compression mode. The weakness of coaxial braces can be corrected by using buckling restrained braces, in which the brace yields in compression without buckling occurring. With the existence of various lateral bearing systems, Buckling-Restrained Braced Frame (BRBF) have a special place in seismic resistant systems due to their high stiffness, optimal energy absorption, and stable cyclic behavior (hysteresis). Due to the lack of buckling, they are able to dissipate a lot of energy and are used in the passive control of structures.

2. Buckling restrained braces

In general, steel braces are divided into two categories: convergent and divergent braces. The capacity of conventional convergent braces is very different in tensile and compression, especially in alternative loading such as earthquakes. Existing converging braces have an acceptable capacity in tensile, but under pressure due to the occurrence of buckling phenomenon, they do not have adequate resistance. In other words, the common convergent bracing system suffers a deterioration in resistance and stiffness in compression mode, while buckling restrained braces show good performance and their hysteresis curve is complete and stable and at the same time symmetrical, and the decrease in resistance and Their hardness is not observed.

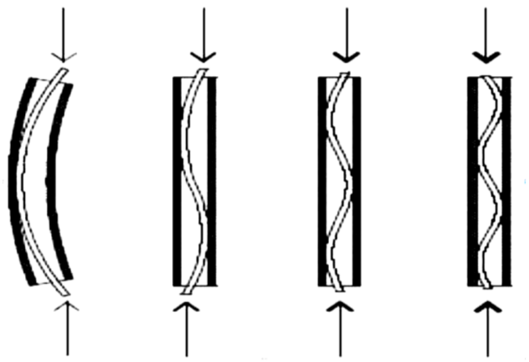

Fig.1.The idea of enclosing the column for more pressure bearing capacity. [2]

The buckling of the compression members of the common braces occurs as an undesirable behavior of the systems under the effect of secondary non-linear geometric deformations and leads to a reduction in the ductility and energy loss capacity of the structure.

Paying attention to this issue is particularly important in periodic loadings such as earthquakes due to the nature of stiffness reduction under seismic dynamic loads. Preventing the buckling of bracing members with the aim of providing compressive yielding has been investigated in India for the first time, about 30 years ago in order to prevent the buckling of columns and the increase of their loading. After that, studies on buckling restrained braces were conducted in Japan in 1980, and in 2000 in America, mentioned braces were used in practice and their application expanded rapidly.

The main principles of the operation of buckling restrained braces is to prevent the occurrence of buckling of the steel core in order to allow the phenomenon of compressive yielding to occur in it and as a result, the possibility of absorbing energy in this member of the structure. This is possible by covering the entire length of the steel core in a steel casing filled with concrete or mortar. In this system, it is necessary to provide a sliding surface or discontinuity layer between the metal core and the enclosing concrete. The main advantage of this work is to raise the buckling mode to the extent that the buckling mode of the brace occurs after the central core has occurred in pressure.

The behavior of frames with torsional buckling restrained braces, despite the appearance similarity, is very different from conventional coaxial braced frames. In the buckling restrained bracing system, the hysteresis cycles are stable and during multiple loading and unloading cycles, no drop in the resistance and stiffness of the system is observed.

3. The history of buckling restrained braces

Buckling restrained braces were first used in Japan in 1989. Today, they are widely used as seismic members in earthquake-prone areas, including in Japan, the United States of America, China, etc. In 1970, a number of researchers in Japan and India reached significant results in their research and presented the basic concepts of buckling restrained braces. Saki, Wada et al., in 1988, used steel tubes filled with mortar to restrain the buckling of the structure, and the first buckling restrained brace was created.

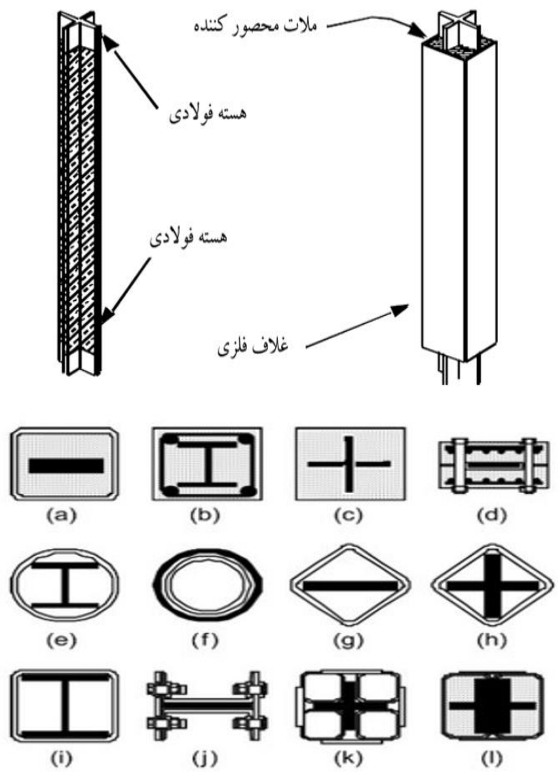

Fig.2.Constituent components and sections used in buckling restrained brace. [2],[5]

The research on buckling restrained braces in Japan and some other countries started about 30 years ago and its idea was improved during this period. The widespread use of this bracing system began after the Northridge earthquake in America in 1994 and the Kobe earthquake in Japan in 2003. By 2003, more than 250 buildings in Japan and 25 buildings in America were built with this system. This research continued after the Northridge earthquake and was expanded and advanced in terms of theory by Clark et al. in 1999, Lopez in 2001, Aiken et al. in 2002, and Sable et al. In our country, Iran, due to its location on the Alpine-Himalaya earthquake belt, research on torsional buckling restrained braces has started about 15 years ago, and its production has been started by private sectors since 2014.

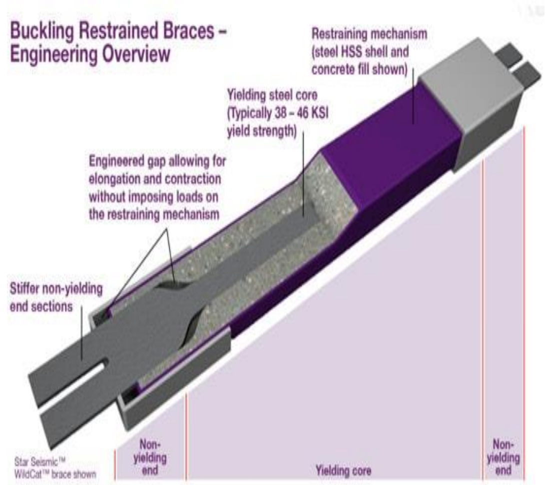

Fig. 3. Different parts of a buckling restrained brace. [https://sabzsaze.com/buckling-restrained-brace]

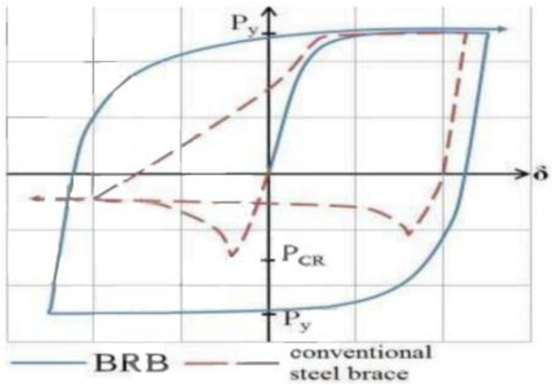

Fig. 4. Hysteresis behavior of conventional braces and buckling restrained. [6]

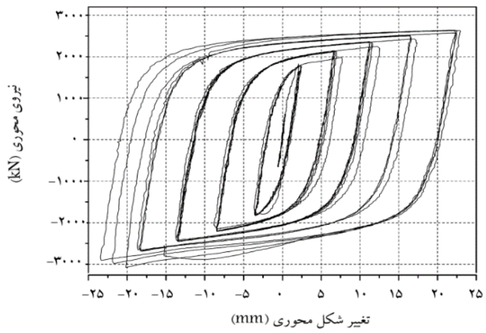

Fig.5. Cyclic curve of steel buckling restrained braces based on laboratory results. [4]

4. Evaluating the seismic behavior of steel structures with buckling restrained bracing by the scaled nonlinear dynamic analysis method

In a research conducted by Mr. Ghodrati Amiri and other colleagues in 2011, the seismic performance of steel frames with buckling restrained braces was investigated by scaled nonlinear dynamic analysis as well as nonlinear static analysis. In this research, a number of 3 and 12 story braced frames with diagonal, transverse, two-part and chevron buckling restrained braces were designed and by considering the effect of the number of earthquake records in the nonlinear dynamic analysis, the dispersion of the results was analyzed and the results show this issue that the non-linear static analysis method overestimated the response values of the buildings in some cases, and the increase in earthquake records did not have much effect on improving the dispersion of the results in the scaled dynamic method

According to the results obtained from this research, it was determined that non-linear static analysis methods have a good ability to estimate roof displacement. However, these methods are not accurate in estimating the parameters between floors (such as displacement and relative displacement), especially in buildings where the effects of higher modes are involved. For this reason, the scaled dynamic analysis method tries to use the strengths of the non-linear static method (in estimating the target location change) and the non-linear dynamic method (in estimating the response values between floors). Of course, it is necessary to note that in this research, only the frames braced with buckling restrained braces have been examined and in order to make a definite opinion about the advantages and disadvantages of this method, more and more extensive researches are needed on other types of building systems. According to the results of the analysis in this research, it can be said:

- The results of this research show that the scaled nonlinear dynamic analysis has a suitable capability in estimating the seismic response of buildings. Therefore, this method is an efficient method when the number of records corresponding to the construction of the building is not available (such as in Iran)

- The comparison of response values of 3 and 12-story buildings in nonlinear static analysis and scaled nonlinear dynamic analysis shows that the static analysis estimates the displacement values, relative displacement and shear of the floors in these structures at the level of high performance. This article can cause uneconomic design or improvement of the structure. However, in order to make a general comment in this regard, it is necessary to examine a wider range of structures.

- In all the buildings used in this research, at the beginning of the nonlinear region (relative roof displacement 0.2%), the response values obtained from the scaled nonlinear dynamic analysis are in good agreement with the responses obtained from the equivalent static load pattern and First mode of the structure in a non-linear static method. However, with the increase in demand, the difference between the answers in the two mentioned methods increases.

- The comparison of 12-story buildings with chevron and diagonal bracing shows that the response values in the scaled nonlinear dynamic analysis method are between the response values of two equivalent and uniform static load patterns (or distribution according to the first mode of the structure). However, using two load patterns according to FEMA356 is not always reliable

  - As the demand increases in the above structures, the dispersion of displacement response and relative displacement resulting from the scaled nonlinear dynamic analysis increases greatly. Also, the results show that increasing the number of earthquake records to more than 5 records in the studied structures does not have a significant effect on reducing the dispersion of the results.

5. Determination of the Parameters Influencing Behavior Factor of Buckling Restrained Braced Reinforced Concrete Frames

In the research conducted by Mr. Tasnimi and Mrs. Dehghan in 2012, the factor of behavior of reinforced concrete frames with buckling restrained braces with four, eight, twelve and sixteen story, each of which has three and five openings was designed and examined in accordance with the ninth topic of the national regulations. In this research, by using OPENSEES software, the buildings were subjected to non-linear static loading and the behavior factor of all frames was calculated for the final limit state.

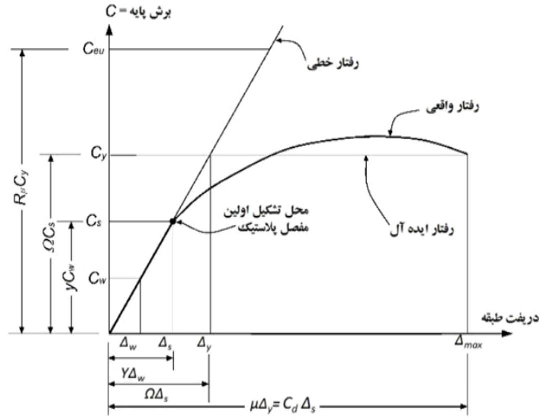

Fig.6. How to determine the behavior factor from the capacity curve. [3]

The results obtained from this research are:

- Among all the studied frames, the ductility factor of frames braced with buckling restrained brace is higher than other systems.

- Among all the studied frames, the ductility factor of frames without braces is lower than other systems.

- The average factor of ductility in frames with buckling restrained braces is around 5.

- The average factor of ductility in frames with conventional braces is around 4.

- The average factor of ductility in frames without braces is about 2.5.

- Frames with buckling restrained braces have higher ductility than other systems.
- The additional resistance factor in braced systems with normal brace and buckling restrained are close to each other.
- The lowest additional resistance factor is related to frames without braces.
- The average factor of behavior obtained for the braced system with buckling restrained brace is about 8.

6. The effect of the yield zone length on the seismic performance of buckling restrained braces

In a research conducted by Mr. Raisi Dehkordi and other colleagues in 2015, the effect of the length of the yield zone on the seismic performance of buckling restrained braces in two groups of short-story and mid-story steel buildings of 5 and 8 stories with buckling restrained bracing frames with 4 and 6 meter spans were studied. In this research, ABAQUS software was used for the nonlinear finite element model.

The results have shown that the reduction of the cross-sectional area of the buckling restrained brace has led to a reduction in the length of the yield zone and the contact surface between the core and the casing, and therefore the frictional force transmitted to the casing has also been reduced, and the length of the buckling region has also been shortened. As a result, the steel casing of the brace can be replaced with a shorter length, which will economically save costs.

Fig.7. 3D figure made in ABAQUS software for buckling restrained brace. [4]

In order to evaluate the seismic performance of structural models with buckling restrained braces, nonlinear dynamic analysis were used and loading was done according to the 2800 standard and with 3 different patterns. Using the earthquake load factor and defining the lateral load uniformly and applying loading were through acceleration mappings which was in accordance with the research conditions of different loading patterns. After performing nonlinear analysis, the obtained results have been compared with the acceptance criteria of braces.

Table 1. Acceptance criteria for buckling restrained braces. [4]

Acceptance Criteria		Performance levels
Nippon Steel	ASCE41-06	
5 Δy	0.25 Δy	Immediate Occupancy
15 Δy	11 Δy	Life Safety
20 Δy	13 Δy	Collapse Prevention

Seismic evaluation of the studied structures in this research based on the results of non-linear analysis about the reduction of material used in buckling restrained braces has led to the following results:

- The narrower the middle section of the opening of the brace is, the length of the yield zone decreases, and as a result, a smaller area of the brace reaches the yield point, and there is stress concentration in a short area, and the reliability factor is greatly reduced. Also, to any extent, the length of the brace increases, the length of the yield zone increases, but the ratio of the yield zone to the length of the brace does not change much. According to the increase in force and the proper performance of the buckling restrained braces, the force is properly distributed in them and the concentration of stress in one area and the creation of critical conditions are prevented.
- by increasing the number of floors and decreasing the cross-sectional areas, the length of the yield zone increases. It can be concluded that due to the increase in the length of the dough region, the stress) is reduced and the reliability factor is

increased, which leads to the improvement of the conditions of using buckling restrained braces in taller structures.

- In the studied models, where the cross-sectional area of the braces has been reduced to 75%, the seismic demand created in the braces has increased to the extent of the change of locations corresponding to the collapse performance levels.

- In the studied models, in which the reduction of the cross-sectional area was 50%, the seismic demand levels in the mid-range models are at the level of life safety performance, but in the short-range models, the seismic demand has been increased to the performance level of the collapse. so, in the mid-range models under the study, the use of buckling restrained braces with a reduced cross-sectional area to the extent of 50% of the initial cross-sectional area, will be appropriate to meet the design goals and to improve with this level of performance.

- In the studied models, where the reduction of the cross-sectional area was 25%, the amount of seismic demand was at the level of life safety performance. Therefore, the use of buckling restrained braces (with a 25% reduction in cross-sectional area) in short and mid-range models will be appropriate to meet design and improvement goals.

- Models with larger openings and with a 25% reduction in cross-sectional area have more absorbed strain energy than the rest of the models, which, compared to models with smaller openings, indicate more energy absorption in the mentioned models. Similar results have been obtained regarding the doughy energy loss of the studied different models.

- Reducing the cross-sectional area of the buckling restrained braces to 25% will result in a 12% reduction in the weight of the used materials, and as a result, will save about 10% in the required costs. Reducing the cross-sectional area to 50% will lead to a reduction in the weight of the consumed materials to about 25%, which will save about 22% in costs. Reducing the cross-sectional area to 75% will cause The weight reduction of the materials used for the buckling restrained braces to about 38%, which will lead to save in the costs related to the buckling restrained braces to about 35%.

7. Investigating the seismic behavior of buckling restrained braces with steel casing without fillers

In a research conducted by Mr. Rezvani Sharif and Mrs. Ghafari in 2016, the seismic behavior of buckling restrained braces with steel casing without fillers was investigated. In this research, 11 buckling restrained braces and one normal brace were modeled in ABAQUS software and behavior of buckling restrained brace models under the influence of the presence of steel casing, no use of filler, the cross-sectional shape of the core of the diagonal members and the thickness of the steel casing under the effect of the same periodic loading, were checked.

- The results of the analyzes show that the energy loss capacity of the buckling restrained brace is about 5 times the energy loss capacity of the normal brace. The ability of dissipate energy and the ultimate capacity of the diagonal member section when using no fillers is reduced compared to the capacity of the section when using fillers, and the core of the diagonal members of the brace with a circular cross-section is more resistant than the two UNP and cross-sectional area.

In this study, 11 samples of buckling restrained brace and one normal brace were modeled and cyclically loaded in ABAQUS software. The results are as follows:

- The use of steel casing increases the bearing capacity of the double UNP brace to about 7%.

- The energy loss capacity in the buckling restrained brace is about 5 times of the normal convergent brace.

- In the sample with a cross section of the core and plate in the state of no filling compared to the state with mortar, because of the creation of buckling waves in the core due to the existence of a free distance between the core and the casing, the final capacity has decreased to about 50-58%.

- By calculating the area of the load-displacement diagram for cross sections and plates, in two cases of with and without filler material, it was observed that the use of filler material in the mentioned samples due to delaying the phenomenon of local buckling of the core, the ability to waste energy has increased up to 4 times.

- In the comparison of three samples with UNP, cross and circular sections, it was found that the energy loss capacity in the section with a circular core is equal to 1.12 and 1.67 respectively, compared to two UNP and cross sectional area.

- In the comparison of three samples with sections of UNP, cross and circular cores, it was found that the final capacity of the sample in the section with circular core has increased by 10% and 21%, respectively, compared to two UNP and cross sectional area.

- In buckling restrained braces without fillers, if the Pe/Py factor is greater than 1, its increase does not have much effect on the ultimate capacity of the section.

- By choosing the appropriate shape and specifications of the core and casing for buckling restrained braces, it is possible to partially compensate for the decrease in strength due to the lack of filler material and increase the capacity of the brace.

8. An Analytical Study of Seismic Performance of a New Type of Reduced Length Buckling Restrained Brace (RLBRB) with S-shaped Core

In a research conducted by Mr. Shafaei and Tahmasabi, the seismic performance of short-length buckling restrained brace with S-shaped core was investigated and analyzed. In this research, a new and innovative idea called a short-length buckling restrained brace with an S-shaped core has been introduced, which despite its very short length can have the same performance as the RLBRB and BRB system and at the same time act as a passive control system. Therefore, firstly, the analytical models of RLBRB and BRBs braces were validated in ABAQUS software based on the laboratory results of past researchers, and then, according to the results of the analysis, the specifications of short-length buckling restrained braces with S-shaped core were compared with RLBRB and BRB braces. The results of comparing the proposed design with conventional buckling restrained braces show that despite being smaller and lighter, these braces have the same behavior as conventional BRB braces.

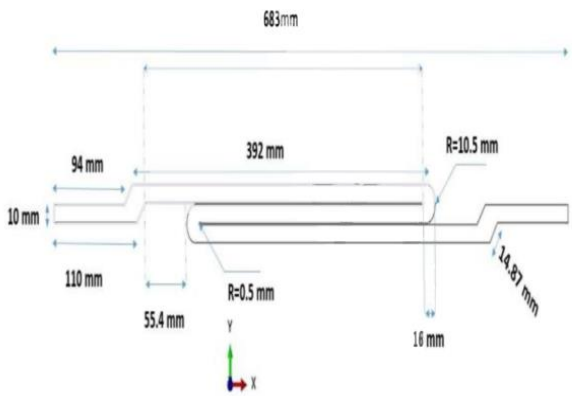

Fig.8. Details of the core of the S-shaped brace. [6]

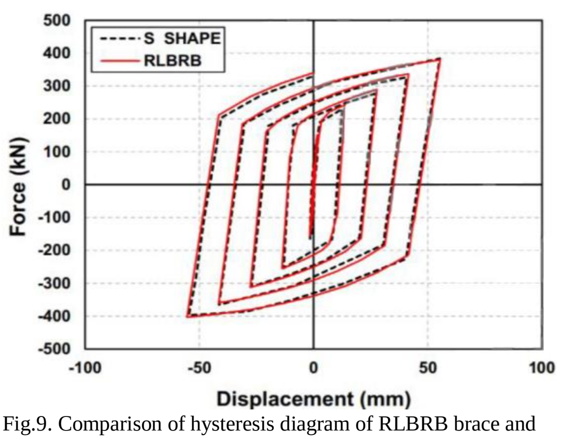

Fig.9. Comparison of hysteresis diagram of RLBRB brace and short length brace with S-shaped core. [6]

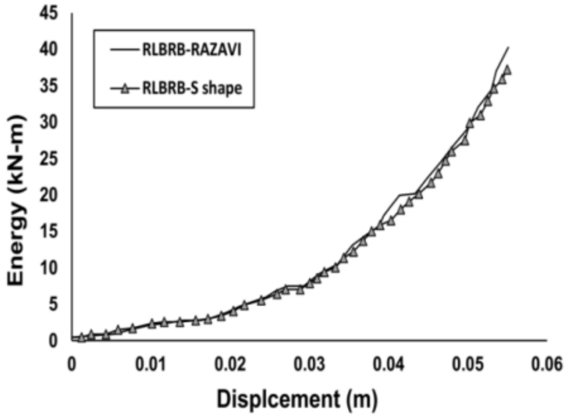

Fig.10. Comparison of cumulative energy loss of RLBRB brace and short length brace with S-shaped core. [6]

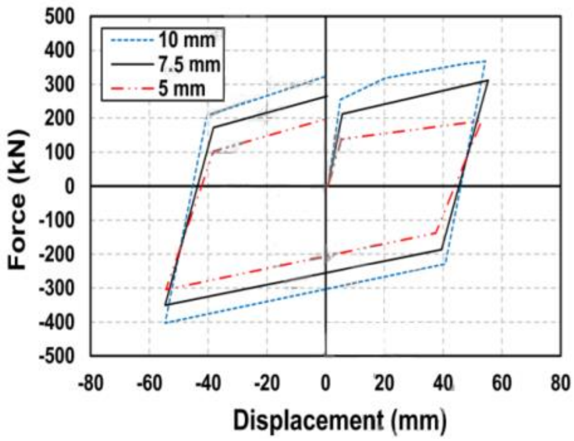

Fig.11. The effect of the core thickness on the hysteresis diagram of the short s-shaped brace. [6]

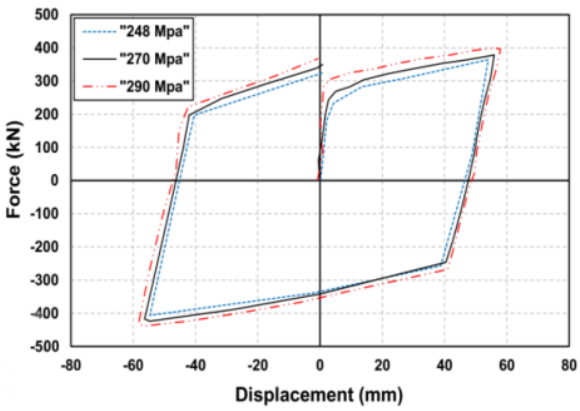

Fig.12. The effects of yield stress on the hysteresis diagram of short length s-shaped brace. [6]

In this research, a new type of short-length buckling restrained braces with an s-shaped core has been presented. The purpose of this research is to solve some of the implementation and performance problems in the common long and short buckling restrained braces. The short length brace with S-shaped core was subjected to nonlinear analysis under the effect of cyclic loading using ABAQUS software. The results of nonlinear finite element analysis show that:

The intended brace showed stable cyclic behavior without loss of strength and stiffness until the end of the ISC 341 standard loading protocol, and no overall buckling occurred in it. Due to the creation of a very small distance between the core and the casing, the local buckling was limited, which itself causes a uniform distribution of stress in the brace. Also, based on the results of the analysis, it was determined that the energy loss of the proposed brace with an S-shaped core is similar to that of common short length braces. Based on the results of this research, short-length buckling restrained braces with a S-shaped core are suggested as an alternative to conventional braces due to their lightweight and easy portability.

9. Results

1) Scaled nonlinear dynamic analysis has a good capability in estimating the seismic response of buildings. Therefore, this method is an efficient method when the number of records corresponding to the construction of the building is not available (such as in Iran).

2) The ductility factor of frames braced with buckling restrained braces is higher than other systems.

3) The average factor of ductility in frames with buckling restrained braces is around 5.

4) Frames with buckling restrained braces have higher ductility than other systems.

5) The average factor of behavior obtained for the braced system with buckling restrained brace is about 8.

6) Reducing the cross-sectional area of the buckling restrained brace has led to a reduction in the length of the yield area and the contact surface between the core and the casing, and therefore the transfer friction force to the casing has also been reduced, and the length of the buckling area has also been shortened. As a result, the steel casing of the brace can be replaced with a shorter length, which will be economical due to cost savings.

7) The capacity of energy loss in the buckling restrained brace is about 5 times that of the normal convergent brace.

8) By choosing the appropriate shape and specifications of the core and casing for the non- buckling braces, it is possible to partially compensate for the decrease in strength caused by the lack of filler material and increase the capacity of the brace.

9) Energy loss of short length brace with S-shaped core is similar to conventional short length braces. Short-length buckling restrained braces with an S-shaped core are recommended as an alternative to conventional braces due to their lightweight and easy portability.

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