A Two-Ring Energy Dissipating Device with Similar Behaviors in Tension and Compression to Create Buckling Resistant Braces

M. Hosseini
International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran

Y. Mirzaaghaee
Fars Science and Research Branch, Islamic Azad University (IAU), Fars, Iran

B. Ebadi Tabrizi
south Tehran Branch, Islamic Azad University (IAU), Tehran, Iran

Summary:
An innovative type of energy dissipating device is introduced, which consists of two steel rings placed together by a specific setting so that the whole device behaves similarly in tension and compression. The setting of rings is such that when the corresponding brace element works in tension one of the rings is under tension and at the same time the other one is under compression, and reciprocally, when the brace element works in compression one ring is under compression and the other one is under tension. The yielding strength of the device under axial action of the brace is adjusted to be a little lower than the buckling strength of the brace to prevent it from buckling. To investigate the structural behavior and energy dissipation mechanism of the proposed device, it has been analyzed nonlinearly by finite element method. Numerical results show the satisfactory behavior of the proposed energy dissipator.

Key words: Ductile steel Rings, buckling Restrained Brace (BRB), Nonlinear Finite Element Analysis

1. INTRODUCTION

The main shortcoming of bracing elements, particularly in concentric bracing systems, is the bucking of braces under compressive loads. To overcome this shortcoming some researchers have proposed the use of buckling restrained braces. In order to obviate the weak point of co-centric braces and secure their desirable ductility, numerous researches has been conducted in the two recent decades, and different methods has been applied to improve the ductility of concentrically braced frames (CBFs). One of the methods is using fuses. Fuses are built in various shapes with different shear, flexural and torsional performance. Most of investigations in this area are done into the flexural performance. One of the types of flexural elements is elbow-knee element and braces with elbow-knee which Balendra [1] did many researches on that during 1970 till 1977. Another method is applying flexural elements, using an element with flexural behavior built from X, rhombic [2] and triangle [3] steel plates. In these elements ST37 is used that they flow in a uniform way due to their suitable shapes. A new kind of these elements is ring element which Abbas Nia. et al [4] did a valuable investigation on. The results showed that this element increases the ductility of co centered braces. However, the load bearing capability of ring element is limited. Besides, with increasing the diameter, the amount of ductility decreases and there would be architecture limitation in the braced span. Also ring behavior in tension and compression is not the same. In this paper, tries to research into increasing the load bearing capability of the ring applying a proposed connection including two steel rings in order to prevent or postpone the brace buckling so that the new element acts as a fuse for diverse loads and prevent other members to enter the nonlinear stage [5].

An alternative way for preventing the braces form buckling is using devices which have similar behaviors in tension and compression. In this paper a relatively new type of energy dissipating device is introduced, which consists of two steel rings placed together by a specific setting so that the whole device behaves similarly in tension and compression, and therefore helps to create buckling resistant bracing elements. The setting of rings in the proposed device is such that when the corresponding brace element works in tension one of the rings is under tension and at the same time the other one is under compression, and reciprocally, when the brace element works in compression one ring is under compression and the other one is under tension. The yielding strength of the device under axial action of the brace is adjusted to be a little lower than the buckling strength of the brace. In this way, the bracing element is prevented from buckling. To investigate the structural behavior and energy dissipation mechanism of the proposed device, it has been modeled nonlinearly in a powerful finite element (FE) program environment by using solid elements with elastoplastic behavior and kinematic hardening state. The modeling process has been verified by using the result of a previous experimental work on single rings. Twenty five set of ring's dimensions combination (the ring's diameter and thickness) have been considered to find out how these parameters affect the hysteretic behavior of the device. For each set of dimensions combination, the initial stiffness, the yielding and ultimate strengths, and the ductility of the device have been obtained by the nonlinear FE model, and the relations between the ring dimensions and their hysteretic behavior parameters have been established in the form of 3-dimensional graphs. These relations can be used for choosing the appropriate ring features based on the expected design loads. Finally, some 2-dimensional steel braced frames have been considered, once with the common x-braces, and once with samples of the proposed device installed in their bracing elements, and have analyzed under cyclic lateral loading. Details of the study are given in the following sections of the paper [5].

2. THE PROPOSED DEVICE AND ITS MODELING

To reach the above mentioned aim, steel rings with radius r, length l and thickness t, in the connection of brace with the corner of the frame is applied. Figure.1 shows the position of the proposed element in the braced frame. Design of the length, diameter and thickness of the element depend on expected axial force in the brace (Figure 2). In addition, the design of the steel ring would be in the way that before buckling in the compressive brace member, the proposed yields and absorbs enough energy to prevent the brace to be buckled [5].

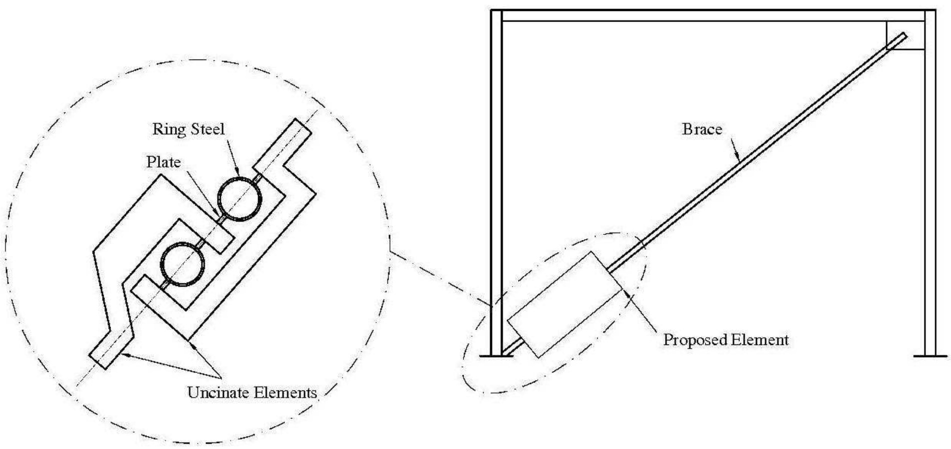


Figure 1. Position of the proposed element in the bracing

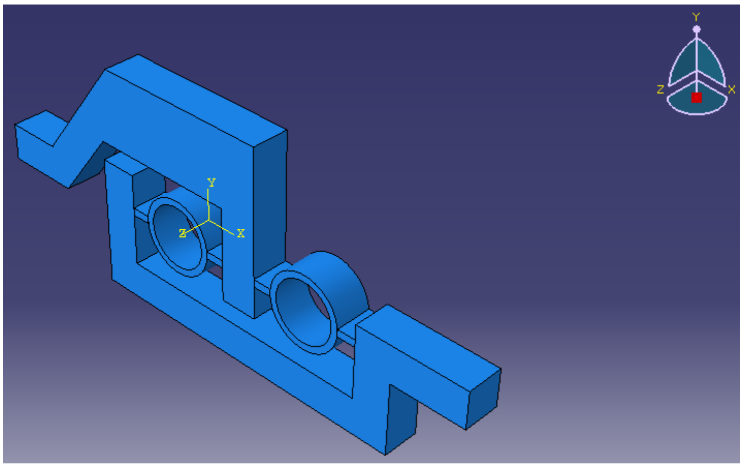


Figure 2. Proposed connection model including yielding steel rings

3. MEMBERS GEOMETRIC AND MECHANICAL PROPERTIES

In this research 25 models from the proposed device were considered. Difference between these models is in the geometric dimensions which include five different diameter and five thickness values. In all the 25 models, dimensions of the gusset plate between ring and uncinate element is PL100x50x20 mm and because the length of all rings are considered 10cm, thickness of uncinate element is 10cm. Table 1 Shows the geometric properties of the rings.

Table 1. Steel rings geometric dimensions.

D (cm)	*t (cm)*	*L (cm)*
15	*1*	*10*
20	*1.2*	*10*
25	*1.4*	*10*
30	*1.6*	*10*
35	*1.8*	*10*

Uncinate elements and steel ring gusset plates are made of st 37. Steel rings are made of a material with the trademark Mannesmann. Members mechanical properties such as stress, ultimate strain, yield stress and elasticity modulus are shown in Table 2.

Table 2. Members mechanical properties.

Type of Steel	*E (kg/cm²)*	e_u	*Fy (kg/cm²)*	*Fu (kg/cm²)*
Ring	*2E+6*	*0.2*	*3000*	*4800*
ST37	*2E+6*	*0.26*	*2400*	*3700*

4. NUMERICAL MODELING AND ITS VERIFICATION

In order to calibrate the proposed connection model in this research, fist a model of steel ring with the properties mentioned in the Table 2 with the diameter 22cm, length 10cm and thickness 1.2cm is built in the software ABAQUS (Figure 3) and loaded by circle loading in accordance with the code ATC40 (Figure 4). As shown in Figure 5, the single steel ring could bear 7.3 Tons in the last cycle of loading. The maximum amount of steel ring diameter change is 2cm. The obtained results are compatible with the empirical ones in the reference [6].

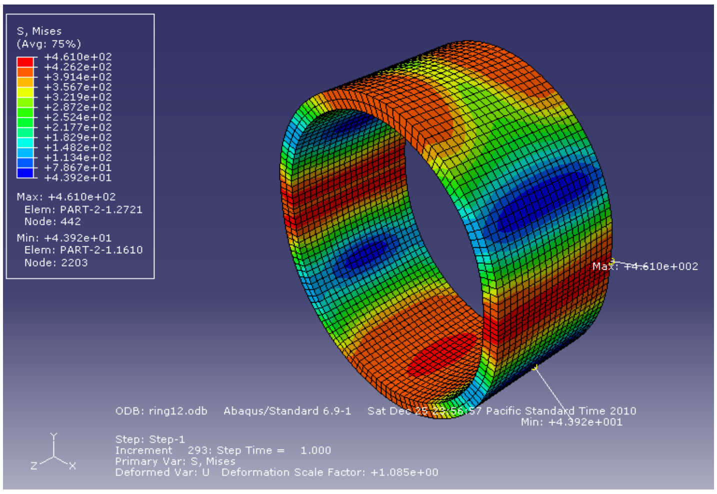


Figure 3. Single steel ring model in ABAQUS

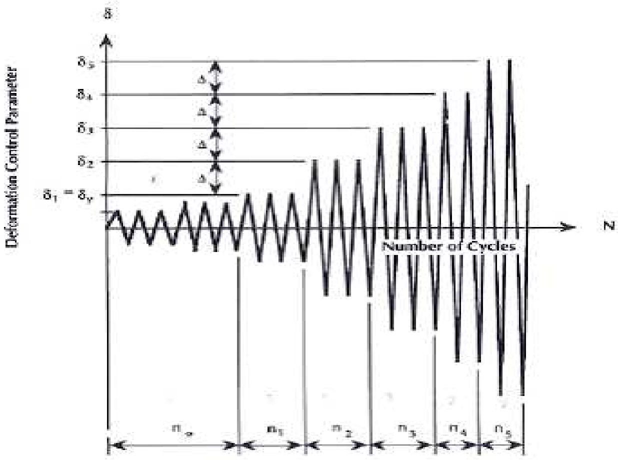


Figure 4. The cyclic load trend, based on ATC 40 applied to the model

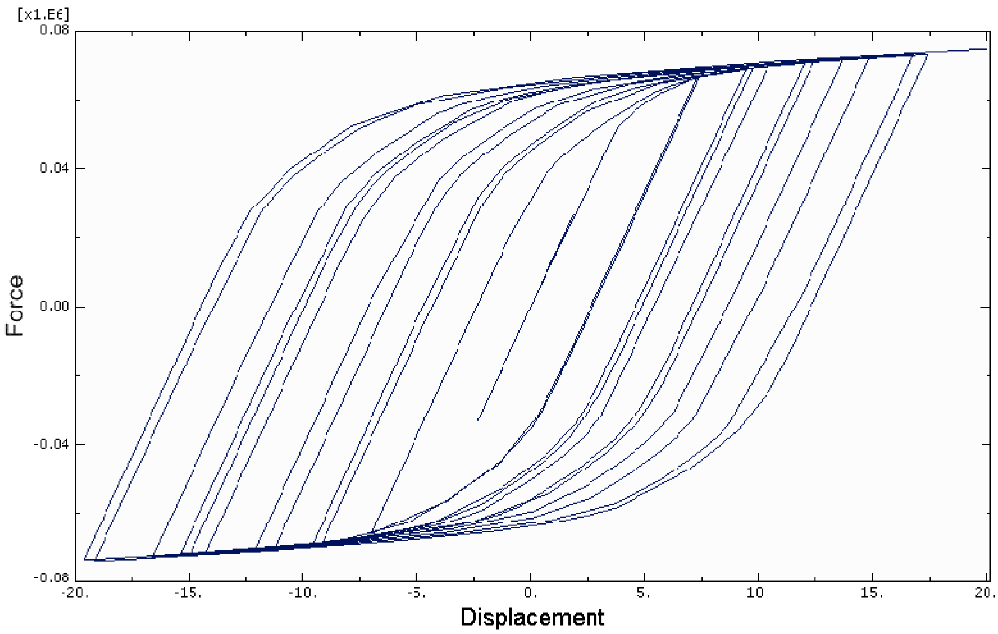


Figure 5. Hysteretic behavior of the a single ring of the proposed device

5. THE PROPOSED MODEL HYSTERESIS CURVE

All the considered models are loaded by the same trend according to Figure 6 and the axial force – axial deformation curves for them are obtained by FE analysis (Figure 7).

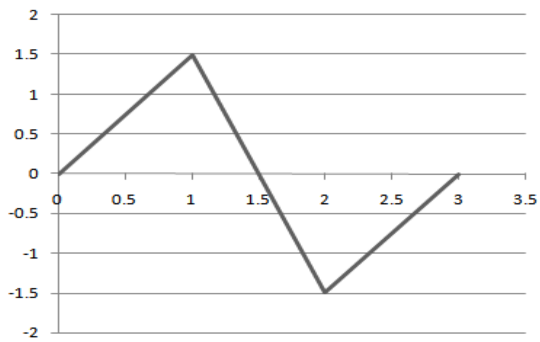


Figure 6. Loading history of the proposed model

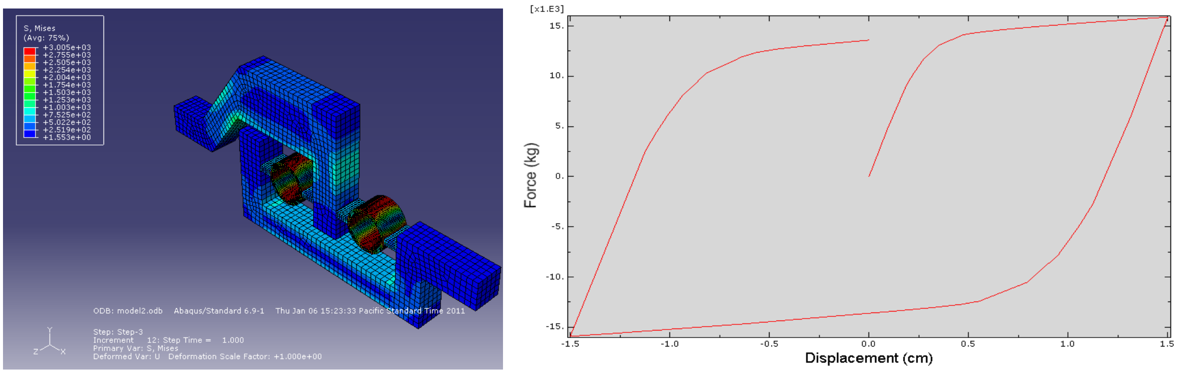


Figure 7. Connection analysis results from the rings with 15cm diameter and 1.2cm thickness

As shown in Figure 8, with decreasing the diameter and increasing the thickness of the ring, the amount of energy dissipation and force would be increased. Using the obtained data, the relation between force and ratio of thickness to diameter of the ring (F-t/D) and also the relation between energy and ratio of thickness to diameter of ring (E/t/D) would be resulted. The obtained relations are shown in Figure 9.

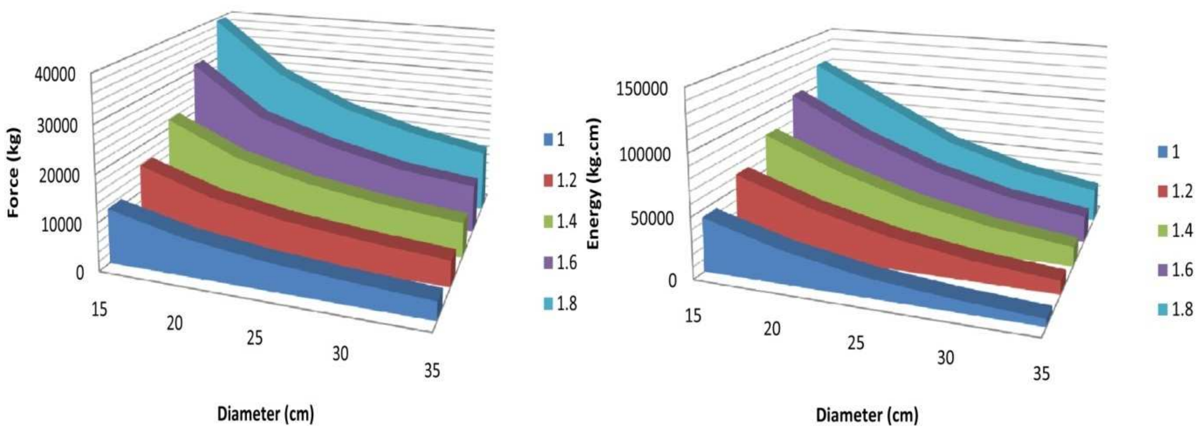


Figure 8. Energy damping and bearable force of the proposed model

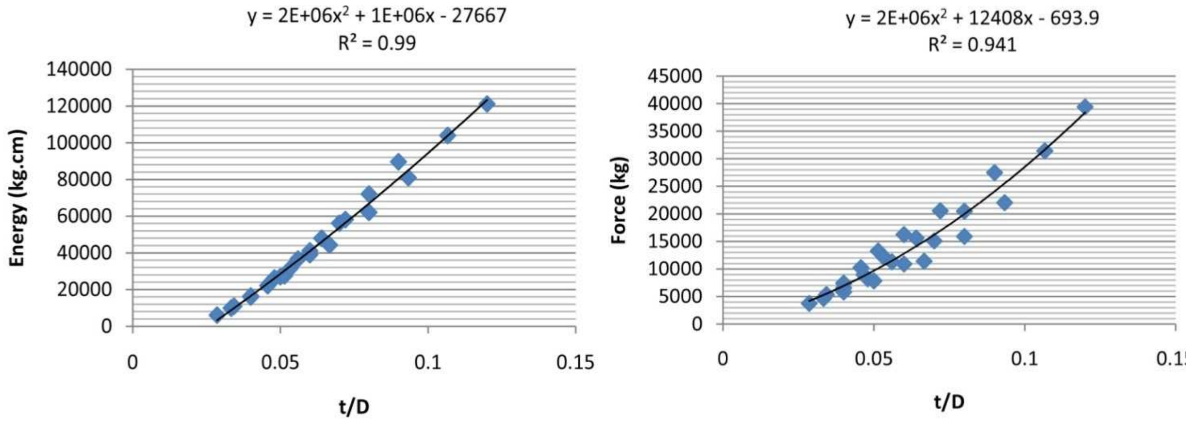
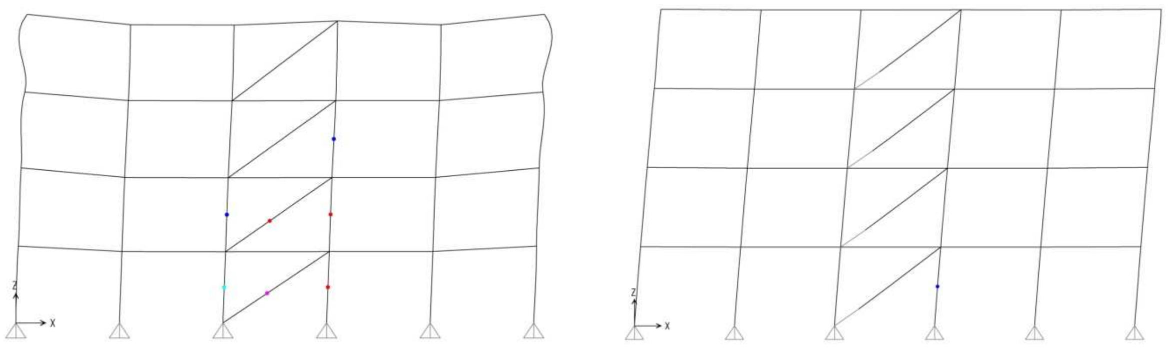


Figure 9. The relation between amount of energy damping and bearable force and ratio of thickness to diameter

6. USING THE PROPOSED DEVICE IN BULIDNG FRAMES

To evaluate the performance of the proposed device in buildings a 2D braced frame with four stories and five spans is modeled in SAP and analyzed nonlinearly once with common bracing and once with the proposed device. For this purpose the frame modeled in the software ETABS and after designing with the Code 2800 3rd edition, members sections are obtained. It is necessary to mention that linear dead load and live load are considered as 2400kgf/m and 800kgf/m respectively. Then the frame is modeled in SAP with common bracing and with the proposed element. After that, nonlinear dynamic analysis (nonlinear time history) is applied by accelerogram Elcentro, Chi-Chi and Kobe.

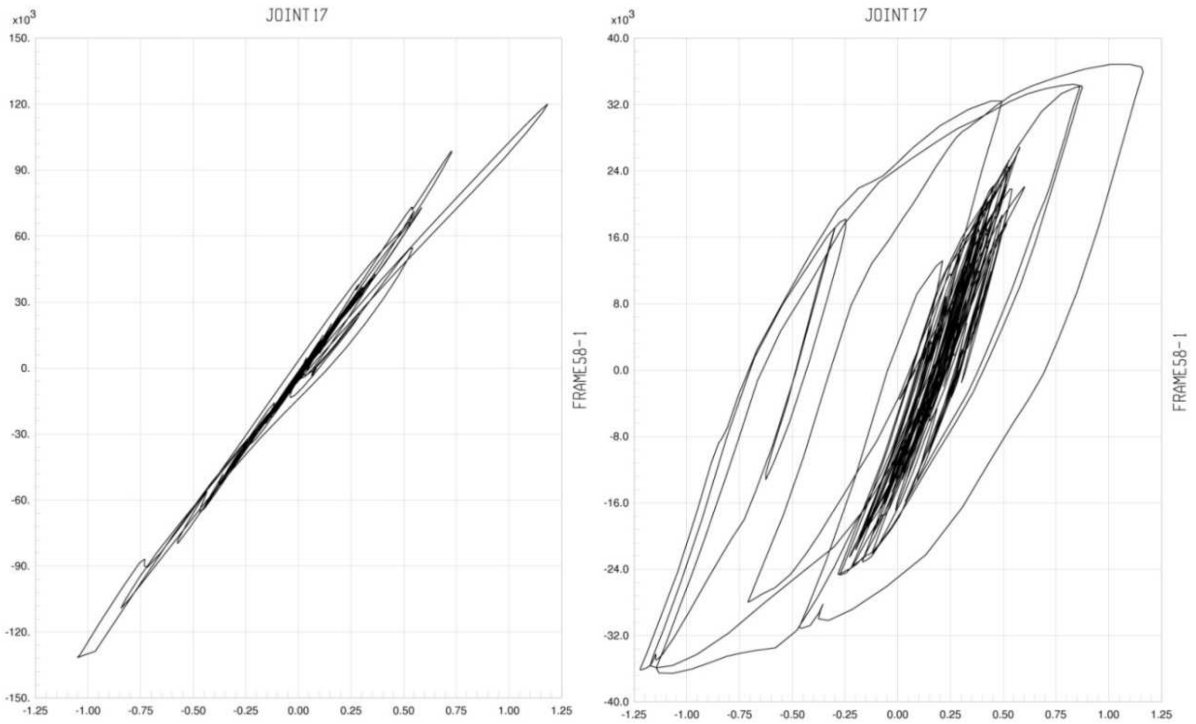
In order to model proposed connection at the end of brace, Multi Linear Plastic-Kinematic is used. Using brace force, ratio of thickness to diameter of ring and hysteresis curves obtained from ABAQUS nonlinear link properties is defined concerning amount of brace force in the software. Nonlinear time history analysis is done on common braced frame and the frame includes yielding ring and in order to compare the results obtained from both frames, axial force – deformation curves, maximum deformation in roof story and maximum base shear in both frames are considered as analysis results. Figure 10 shows both kinds of frames subjected to El Centro earthquake, and Figure 11 demonstrates brace hysteresis at ground floor level.



a. Frame with common bracing

b. Frame with proposed device

Figure 10. Plastic hinges in the two frames subjected to El Centro earthquake



a. Frame with common bracing

b. Frame with proposed connection

Figure 11. Axial force – deformation of braces in the two frames at ground floor level

As it is seen in Figure 11, hysteresis curves for the frame with the proposed device has much wider loops than the frame with common bracing. Another important point is the way in which plastic hinges form. According to Figure 10, plastic hinges are created in the columns located in both sides of bracing and the frames approached collapse state, while in the frame with the proposed device the plastic hinges are created only in one of the ground floor columns in IO performance level. It demonstrates the desired behavior of the proposed energy dissipating device. Finally, Table 3 shows a comparison between the roof maximum displacement and maximum base shear force in both of frames.

Table 3. Comparison of roof maximum displacement and maximum shear force of the two frames subjected to the three considered earthquakes

Earthquake	Frame	Base shear (tons)	Roof displacement (cm)
El Centro	Bracing with proposed device	28.5	7.75
	Common bracing	98.9	8.71
Chi-Chi	Bracing with proposed device	30.96	11.14
	Common bracing	98.17	16.26
Kobe	Bracing with proposed device	38.57	7.07
	Common bracing	60.9	5.10

It can be seen in Table 3 that the base shear in the frame with proposed device is 35% less than that of the frame with common bracing. Also, the roof floor displacement in the frame with the proposed device is mostly is less than that of the frame with common bracing.

7. FINAL RESULTS AND CONCLUSIONS

In this research it was attempted to increase ductility of concentric bracing using a device which have suitable capability and could be provided and installed easily at the end of concentric bracings. The analytical study showed that yielding of steel rings as a ductile member in the proposed device is a suitable option because it absorbs lots of energy, does not let the brace to buckle, and leads the brace to behave the same way in tension and in compression. Also, it is feasible to install it in diverse kinds of concentric braces. The results of this research can be summarized as follow.

1. By decreasing diameter and increasing thickness of the ring, bearable force in brace and energy dissipation capacity both would be increased.
2. Relation between bearable force and energy dissipation with thickness of steel ring obtained with the regression more than 95% which can be a designing reference for engineers.
3. The proposed device could be designed for wide range of loadings according to ratio of different diameters and thicknesses and physical and mechanical properties of different steels.
4. Manufacturing and installing the proposed device is simple and does not require any high professional work.
5. Replacing the damaged device in case of large earthquake would be cheap, simple and fast.
6. Choosing different geometrical dimensions of ring is crucially import and if a strong one is chosen, energy dissipation would be low, plastic hinge would not be formed properly, and hysteresis curve would be completely different.
7. The results obtained from time history analysis in SAP software are as follows.

*In frame with ordinary brace, the brace remained in the elastic range and plastic hinge occurred in the columns at both sides of brace.
*Frame with ordinary brace even failed to meet the requirements of Life Safety level in Design Base Earthquake (DBE) and columns placed on ground and first floors approached collapse level.
*Frame with yielding device could meet the requirements of IO in DBE.
*The amount of base shear in frame with yielding device was 35 percent of that of the frame with ordinary brace.
* The amount displacement in frame with proposed element is less than the frame with ordinary brace in most cases.

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