Analytical Study of Steel Ring Connections as Hysteretic Metallic Damper

Mehrtash Motamedi & Maryam Hafezi
Islamic Azad University, South Tehran Branch, Tehran, Iran

Mohammad Yekrangnia
Sharif University of Technology, Tehran, Iran

15 WCEE
LISBOA 2012

SUMMARY:
In this paper the finite elements model of the Steel Ring Connection (SRC) as hysteretic metallic damper is presented and the effect of the ring geometry on the response of the system is described. The SRC system consisted of the X-bracing system with a steel ring element at the mid-joint connection and was used in the existing steel frames to enhance the lateral ductility, energy-dissipation and damping potential. The SRC system yielded in lateral displacement mechanism of the frame and dissipated energy due to forming of plastic hinges in the ring. The objectives of developing the analytical model were prediction of inelastic response of the SRC with different geometry and study the performance of this system in seismic upgrading of the existing frames. The studied models were including of: rings with different diameter, thickness and width; brace elements with different stiffness; and systems installed in frames with different aspect ratio. To carry out the analytical study of the SRC system the finite elements models were verified with the test results obtained from the similar system studied in previous works and calibrated to represent the identical inelastic load-deformation response of the tested specimens. Nonlinear quasi-static reversed cyclic analysis were performed on the models to study the behavior of the SRC system for low number of cycles with high amplitude demand deformation of the frame corresponding to 2% drift. As results, hysteretic load-deformation response, lateral strength, initial stiffness, equivalent effective damping and dissipated energy in reversed cyclic motions were compared for the SRCs with different geometry and performance of this system for seismic upgrading the frames with different aspect ratio and with different brace characteristics was evaluated.

Keywords: Steel Ring Connections, Hysteretic Metallic Damper, cyclic behaviour, parametric studies

1. INTRODUCTION

Many structures experience inelastic response during earthquakes and in doing so reducing their base shear demand. However ductility in these structures plays an important role and should be given special attention. There are numerous methods in improving the seismic performance of structures specially providing extra and ductility. These methods in order to maintain structures service and performance should possess some important factors including stiffness, ductility and energy dissipation capacity. The braced frame systems develop more seismic loads because of their higher stiffness compared to moment frames, but this feature helps in reducing the displacements. Moreover, their simple connections make these structural systems a simple, feasible and economical method.

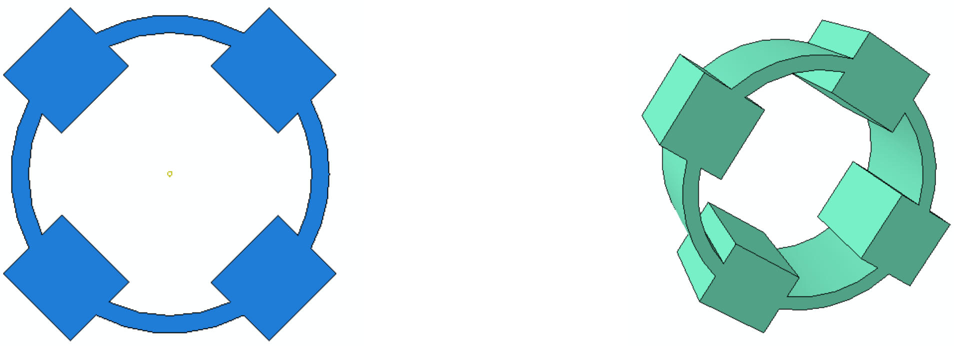
It is noteworthy that among the various types of braced frames, the concentric braced frames (CCBF) are one of the most common types being utilized. However this structural types lacks ductility and there are numerous studies aiming at providing CCBF's with acceptable ductility. One of these methods includes using energy dissipation fuses. There are several types of these elements designed for flexure, shear and torsion. Among the flexural fuses, the knee elements can be mentioned and Balendra did several works in this area from 1990 to 1997. X-shaped steel plates as flexural fuses are the other types of these elements which take advantage of uniform yielding of steel. The ring elements are the new flexural fuses which can be installed in CCBF's. Abbasnia et al. and Wetr et al. did some works on the performance improvement of CCBF specimen which approved the efficiency of this system.

In this paper, a parametric study on the performance improvement of CCBF's which has been added the ring fuses in performed. These elements prevent braces from yielding and bucking which results in increase in energy dissipation capacity and ductility of the system. The studied parameters are diameter, thickness and length of the ring fuses on the ductility, strength and energy dissipation capacity of the system is studied.

2. GEOMETRICAL AND MECHANICAL CHARACTERISTICS OF ELEMENTS

Figure 1 shows how the flexural element (SRC) is installed in CCBF and the 3D view of this element is depicted in Figure 2. The thickness, length and diameter of this element are 9.25mm, 90mm and 168mm, respectively.

Figure1. Installation of SRC in CCBF



(a) (b)

Figure2. Views of SRC (a) 2D (b) 3D

For verification of the numerical model, an experimental test is considered and the mechanical properties of the material and the hysteretic curve are presented in Table 1 and Figure 3, respectively.

Table1: Mechanical properties of the material

Yield strain	Ultimate strain	Yield stress (MPa)	Ultimate stress (MPa)
0.002	0.2	380	570

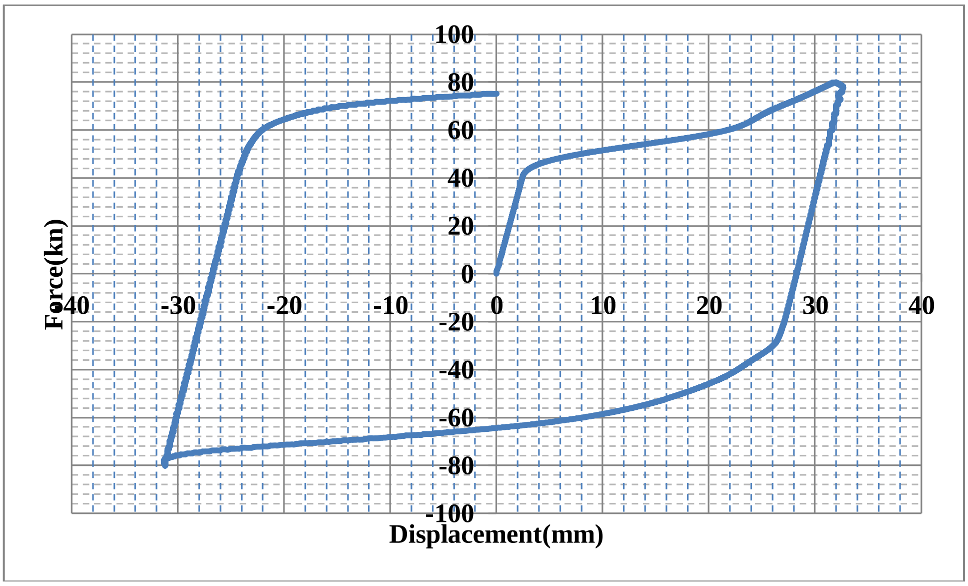


Figure 3. Hysteretic curve of SRC in CCBF

3. MODELING AND STUDY OF PERFORMANCE OD SRC

Two different models (2D and 3D) are studied with the aid of ABAQUS. Since in the experimental work, the beams and columns were connected by simple connections, truss elements are utilized in the model. In 2D model, the SRC are modeled with plane stress elements. Considering the matching of the results of the two models, 2D model is considered for parametric study since it poses less computational cost.

It is noteworthy that the stress-strain curve of the material is assumed to be 3-linear with the hardening effect and with kinematic hardening formula. The Young's modulus of material and the Poisson's ration are 200GPa and 0.3, respectively. It is worth mentioning that since the considerable nonlinearity of the model in material and geometry, explicit method is utilized for this study.

Figure 4 compares the hysteretic curve of the experimental and numerical studies. The results of this figure indicate the numerical model can capture the performance of CCBF with SRC with an acceptable accuracy. As can be seen from this figure, SRC can successfully increase the energy dissipation capacity of the system with stable cycles by yielding. Figure 6 shows forming 8 plastic areas in the inner and outer edge of the washer in the ring fuse increases the load bearing capacity and ductility of the ring without washer. Also the elliptic deformed shape of the ring stabilizes the stresses in the braces and postpones their buckling. Also since the stresses in the ring in the thickness are almost the same, plane stress assumption can be made for the system.

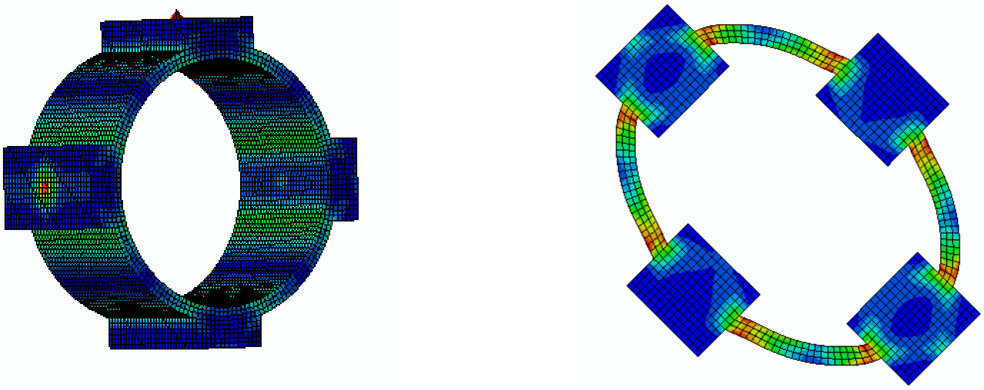


Figure 4. Deformed shape of SRC in 2D and 3D models

4. PARAMETRIC STUDIES

In this section, the effect of ring geometrical features on the performance of the specimen in terms of load-displacement behavior (e.g. initial stiffness, yield and ultimate strength and displacement) is studied. It is noteworthy that lateral load of 80kN are exerted to all the models.

4.1. Effects of diameter of SRC

Three different diameters (168mm, 220mm and 294mm) are considered for study and the related results are summarized in Table 2. It is observed that increasing the diameter results in increasing the ductility. Decreasing the initial stiffness and decreasing the yielding strength of the system.

Table2: Effects of diameter of SRC

Diameter (mm)	D_y (mm)	F_y (KN)	D_u (mm)	F_u (KN)	Ductility	K1 (KN/mm)
168	3	45	33	78	11	15
220	5	31	69	45	14	6
294	7	25	105	38	15	4

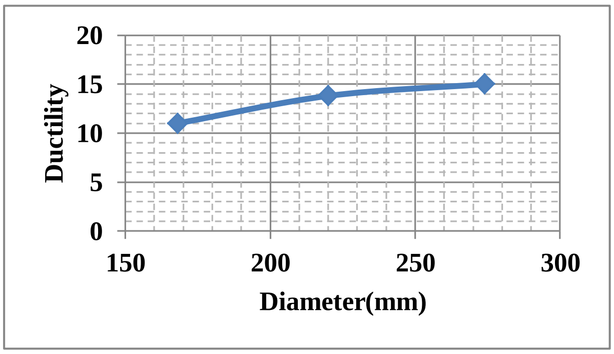


Figure 5. Effect of diameter on ductility

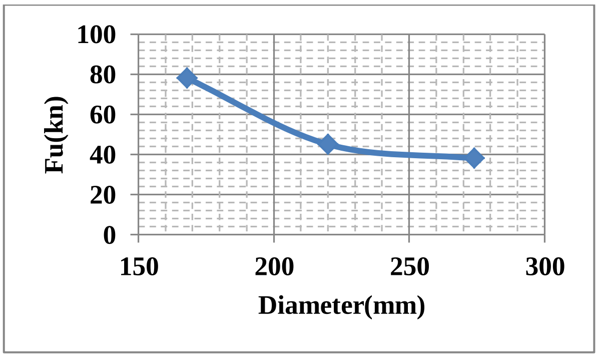


Figure 6. Effect of diameter on ultimate strength

4.2. Effects of length of SRC

Four different lengths (60mm, 75mm, 90mm and 105mm) are considered for study and the related results are summarized in Table 3. It can be seen from the results that by reducing the length of SRC, the initial stiffness, yielding strength and ductility of the system decrease; while the ultimate displacement increases.

Table3: Effects of length of SRC

length (mm)	D_y (mm)	F_y (KN)	D_u (mm)	F_u (KN)	Ductility	K1 (KN/mm)
105	3	50	28	83	10	15
90	3	45	33	78	11	15
75	3	38	39	65	13	13
60	3	30	46	55	15	10

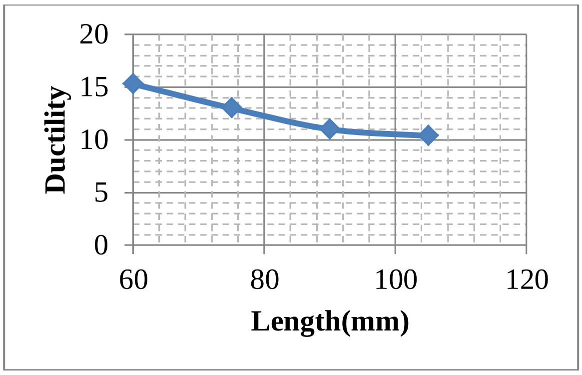


Figure 7. Effect of length on ductility

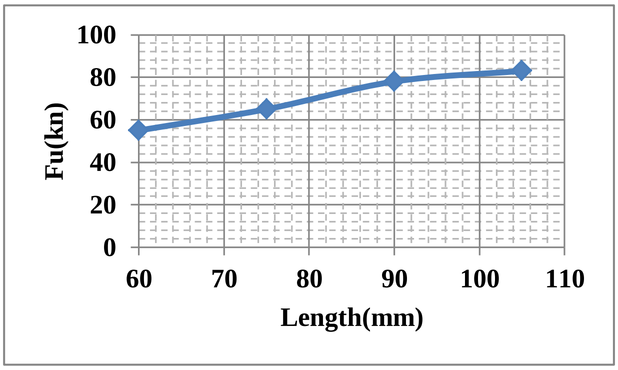


Figure 8. Effect of length on ultimate strength

4.3. Effects of thickness of SRC

Four different thicknesses (7mm, 8.25mm, 9.25mm and 10.25mm) are considered for study and the related results are summarized in Table 4. Increasing the thickness of this element causes increase in initial stiffness and yielding strength and decrease in ductility and ultimate displacement.

Table4: Effects of thickness of SRC

Thickness (mm)	D_y (mm)	F_y (KN)	D_u (mm)	F_u (KN)	Ductility	K1 (KN/mm)
7.00	2	25	50	48	20	10
8.25	3	38	42	63	14	13
9.25	3	45	33	78	11	15
10.25	3	57	25	85	9.6	22

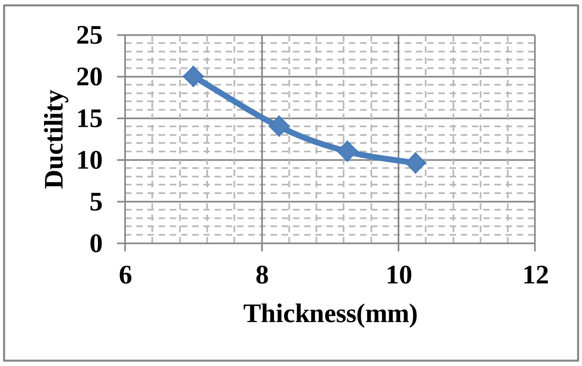


Figure 9. Effect of thickness on ductility

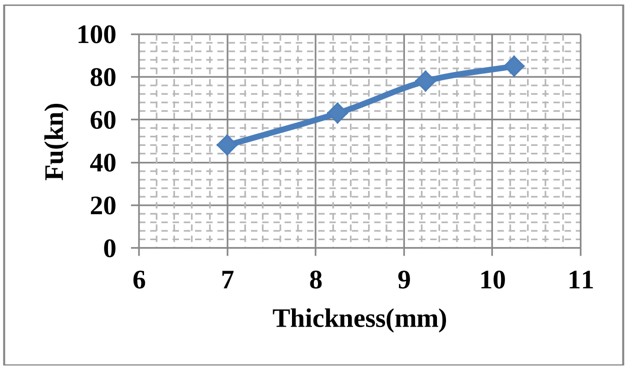


Figure 10. Effect of thickness on ultimate strength

5. CONCLUSIONS

- The ring element which is a simple section of a pipe can be utilized easily and cheaply for performance improvement of CCBF’s.
- Due to considerable ductility and energy dissipation capacity of the ring element from its plasticity, it can be concluded that adding this ring to the system greatly enhances system’s seismic performance.
- The rings with washers showed better response and it was from forming 8 plastic areas which is more that the rings without washer.
- Since the maximum load bearing capacity of the brace elements is the same as the ring, their design can be in the way that prevents braces from buckling.
- There are only three geometrical characteristics of ring elements which can be selected according to meet the design requirements. This feature adds to the simplicity and feasibility of the proposed system.
- The main advantage of the proposed system is its capability in maintaining the level of the loads in brace elements and by initiation and evolution of plasticity with large-area hysteretic loops, prevents them from tensile failure or buckling.

REFERENCES

ABAQUS Documentation,version 6.10

Abbasnia R.,Vetr M.GH. and Kafi M.A. (2005), ”Study of Effect of Ductile Element of Steel Concentric Braced frame” (Persian)

Balendra T., “Large-Scale Seismic Testing of Knee-Brace-Frame”, JOURNAL OF STRUCTURAL ENGINIERING, January 1997, p.p 11-19.

Hafezi M. (2012) ”Analysis of Ring Hystertic Damper and Use in Many Stories Frame” Master thesis Iran-Azad University-South Branch

Kafi M.A., Abbasnia R., (2008, ”Exprimental and Analytical Study of Ductility of Braced frame with Steel Ring Element” (Persian)

Keh-Chyuan Tsai,M.EERI,Huan-Wei Chen,(1993),”design of steel Triangular Plate Energy Absorbers for Seismic-Resistant Construction”, journal of Earthquake spectra,vol.9,no.3.

Khalkhali A.,(2007) ”Finite Element Analysis with ABAQUS”

Ming-Hsiang Shih,Wen-Pei Sung, “A model for hysteretic behavior of Rhombic low yield strength steel added damping and stiffness”, journal of computers ans structure, 83(2005) 895-908

Timoshenko ”Theory of Elastic Stability” 2nd edition,Mc Grow-Hill,1982