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Effect of Annular Damper Thickness and Diameter on Knee Brace Ductility

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ABSTRACT

Much research has been focused on the ductility of concentrically-braced frame**s** (CBFs) in recent decades. Steel rings are ductile elements that are analyzed at the time of connection between the brace plate and the corners. Studies have accurately revealed the function of a steel ring as an energy absorption element and buckling control fuse. This study examined the effect of ring thickness and diameter on the bearing capacity and ductility of a frame and validated the model using laboratory samples and finite element software. The findings reveal a direct relationship between ring thickness and bearing capacity. Conversely, an increase in diameter decreases the bearing capacity. The function of solid and hollow steel rings were investigated by solidifying them with a circular plate. The results suggest that hollow steel rings are effective for knee frames. These findings provide information about ring thickness and diameter options for future design of buildings.

KEYWORDS: Energy dissipation, Steel ring, Concentrically-braced frame, Resistance

1. INTRODUCTION

The unlinear behavior of members and their connections during seismic events result in ductility of the constructs. The wide scope of resistant elements in the overall construction facilitates their restoration after seismic events. Concentrically-braced frames (CBFs) have a limited number of sensitive members compared with special moment frames, nevertheless, their ductility is not satisfactory. A large number of studies have focused on this problem in recent decades. All methods proposed are assumed to increase the ductility of these frames. One method is an energy dissipation. The energy-dissipating member feasibly enters the plastic stage and avoids or postpones destruction of the structure by absorbing a maximum amount of energy. One such dissipation is a yielded steel ring, known as an annular.

Studies reveal that yielded steel rings as ductile members in braced connections absorb energy and are a proper option because they allow the frame to buckle, have identical behavior under pressure and tension, and can be installed in all types of CBFs. Abbasnia et al. (2009) conducted laboratory testing and proposed that steel rings should be used at points where the CBF members are connected to a corner connection plate [1]. They attempted to improve and strengthen the proposed steel ring [2]. Mirza-Aghaee and Hosseini (2012) proposed a new steel dissipation that includes two steel rings, one of which is used for tension and one for pressure [3]. In all studies, steel rings effectively acted as energy-absorbing elements and brace-buckling fuses.

At the onset of a seismic event, the steel ring at the end of a brace can be damaged by plastic deformation and require restructuring. This repair is limited to the brace corner connection and steel ring substitution. In this study, the frame was strengthened by putting one can-shaped steel ring into the CBF without a connection surface. The function of the steel ring was examined using a circular plate to solidify the hollow steel ring.

To validate modeling accuracy and the finite ABAQUS software results, a laboratory sample was examined as suggested by Balendra et al. [4].

2. Preposed Annular Element

To increase the ductility of knee braces, a ring with radius r, length L, and thickness t was used at the points where the brace is connected to the beam and column. Figs. 1 and 2 show the annular element placement in the brace frame and the proposed ring, respectively. The steel ring yields prior to buckling of the brace pressure member and prevents or postpones brace buckling by absorbing sufficient energy.

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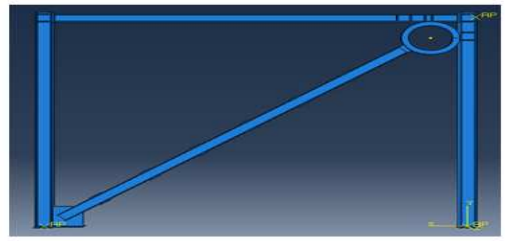


Fig 1.The Annular element Placement in The Brace Frame
Fig 2. The Proposed ring

3. Geometric and Mechanical Properties of The Members

This study tested 24 models with the proposed connections having different geometric dimensions for the ductile steel rings. Radiuses of 150, 220, and 250 mm and thicknesses of 8, 10, 12, 14, 16, 18, 20, and 22 mm were tested. The length of all rings was 50 mm. Table 1 shows the geometric properties of the other elements. The C-channel brace was doubled. To avoid movement of the two profiles away from each other, two plates (100×100×12) were used at a distance of 500 mm on both sides. The brace was connected to the ring by a plate of 116×100×16 mm. The columns and beams were built in channel I. All elements were A36 frame. Their mechanical properties are shown in Table 2.

Table 1. Geometric Details of the Brace Frame Elements

Element Typology	beam	Column	The Brace
Unit	Mm	Mm	mm
depth	100	125	100
width	100	125	50
thick	8	9	7.5
web	6	6.5	5

All applied elements are A36 Frame. Their mechanical properties are included in Table 2.

Table 2. Mechanical Properties of A36 Steel

	Yield stress	Ultimate stress	Young's Module	Density	Poisson's Ratio
Unit	N/mm^2	N/mm^2	N/mm^2	t/mm^3	-
Value	252	406	200e3	7.86e-9	0.3

4. Validation of ABACUS Modeling

The simulation results using ABAQUS were validated by modeling a laboratory sample as suggested by Balendra et al. (1993). This laboratory sample was a knee brace frame with linear knee membership I, a depth of 50.2, width of 48.6, flange thickness of 6, and web thickness of 4.4 mm. All frame elements were built in a tridimensional, ductile, and solid manner using finite element software. All of the support was fixed based on the laboratory model. Because the force of the piston in the laboratory could not be extracted, to produce hysteresis curve results for the laboratory model, loading was applied by cyclic displacement in the z direction towards the highest corner of the column.

Replacement in the laboratory (15 mm) required 32 steps. To create pseudo-static bearing conditions, general statics were taken into consideration by activating nonlinearity. The results of ABAQUS were consistent with studies by Balendera et al. (1993) [4] as shown in Table 3 and Fig. 3.

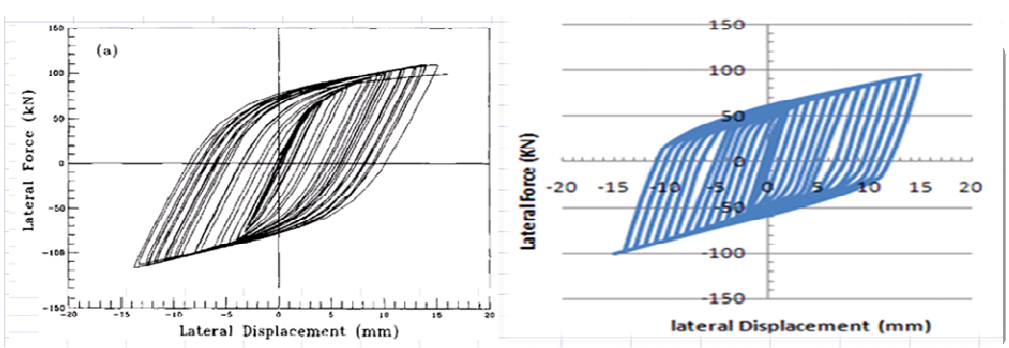


Fig 3. Hy**steresis** Curve (Force-Displacement): The Created Model of The Software (Right curve) and The Laboratory Model (Left curve)

Table 3. Elastic Stiffness- Maximum of Ultimate and Elastic Displacement - Ductility

	Elastic Stiffness (KN/mm)	Maximum of Elastic Displacement (mm)	Maximum of Ultimate Load Displacement (mm)	Ductility
Laboratory Model	24.4	2.4	15.1	6.29
ABAQUS	23.66	2.24	15	6.69
Error Rate	0.03	0.067	0.0066	0.06

5. Steel Ring Function Analysis and Modeling

To calibrate the proposed connection model, a steel ring model was built with a radius of 220 mm, thickness of 12 mm, and diameter of 50 mm in accordance with the frame element properties in the finite element software and maintained under single and cyclic bearing. Fig. 4 compares the ring and knee member. The open and stable hysteresis loops of the ring were created with the knee member. The hysteresis curve results indicate that the frame load capacity of the steel ring was larger than for the knee element frame (laboratory model in ABAQUS), which is an indication of higher dissipation of ring energy and is more effective behavior.

A comparison of the single bearing frame and the laboratory model suggests accurate functioning of the steel ring. The results shown in Table 4 indicate the high bearing capacity of the ring relative to knee member I.

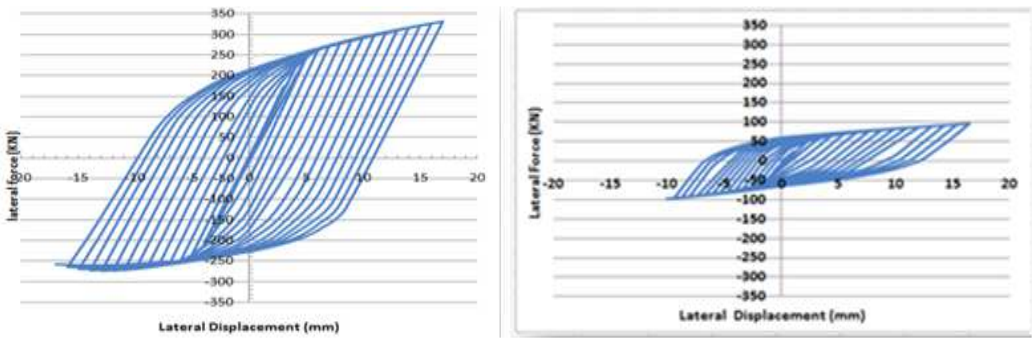


Fig 4. HysteresisCurve: Laboratory Model of ABAQUS (Right curve) and Steel ring Frame (Left curve)

Table 4. Elastic Force – Plastic Force and Elastic Displacement

	Elastic Force (KN)	Plastic Force (KN)	Elastic Displacement (mm)
Steel ring	164.8	242.91	4.35
Laboratory Model	38.6	71.9	1.73

The von Misses stress contour (Fig. 5) shows that the brace did not buckle and the highest stress was allocated to the ring itself. These stresses were greater in the internal damper flange in proximity to the connection between the frame and damper. All parts of the damper yielded and dissipated the input energy by making plastic transformations. This relatively uniform spread of stress suggests the high capacity of the annular damper during dissipation of energy. The annular element acted more effectively in knee brace frames than with a linear element.

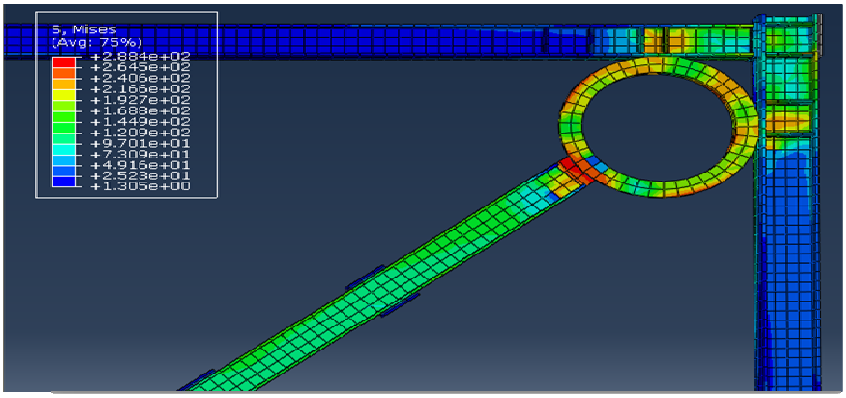


Fig 5.Von Misses Stress Cantor of The Steel ring

The performance of the solid and hollow steel rings were assessed by attaching a circular sheet (r = 170 mm) for the solid ring. The von Misses stress caused by the solid ring shows that the greatest stress is borne by the brace and

the lowest stress to the solid ring. This ring lacks sufficient ductility and was destroyed during major deformation of the buckled brace.

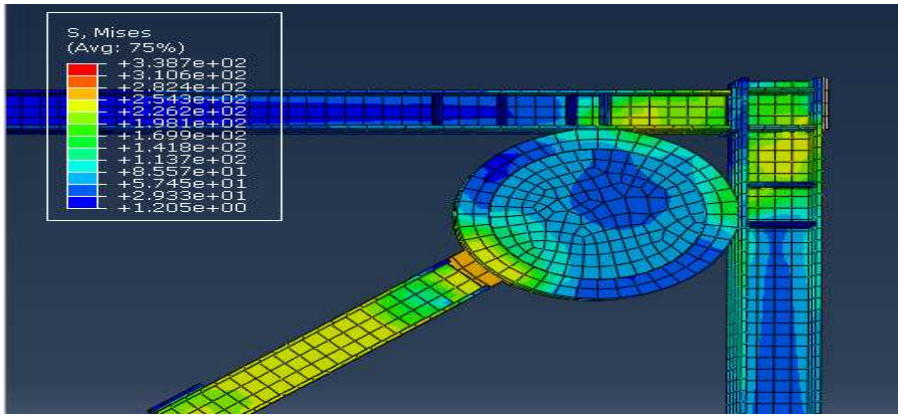


Fig 6. Von Misses Stress Cantor of The Solid Steel ring

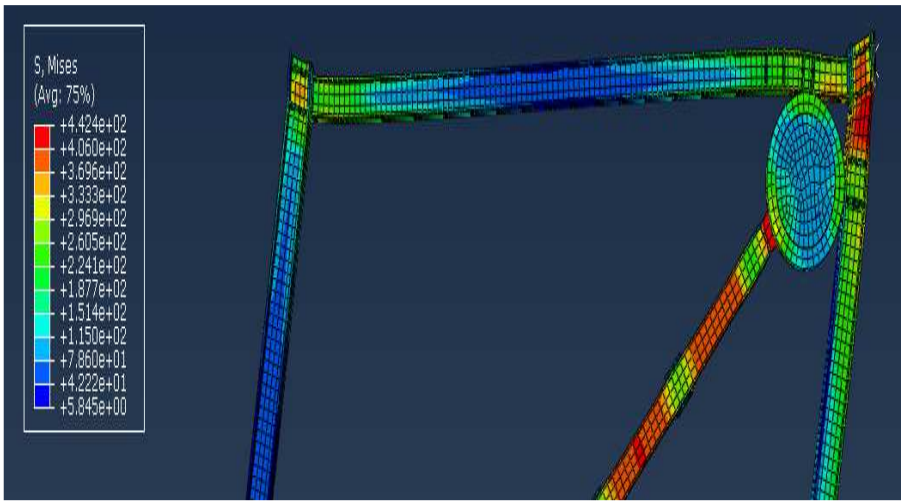


Fig 7. Von Misses Stress Cantor of The Solid Steel ring during 500 mm Displacement

6. Results

After validating the accurate functioning of the steel ring, the force-displacement curves were extracted as output results using all models with different radiuses and thicknesses under identical bearing processes.

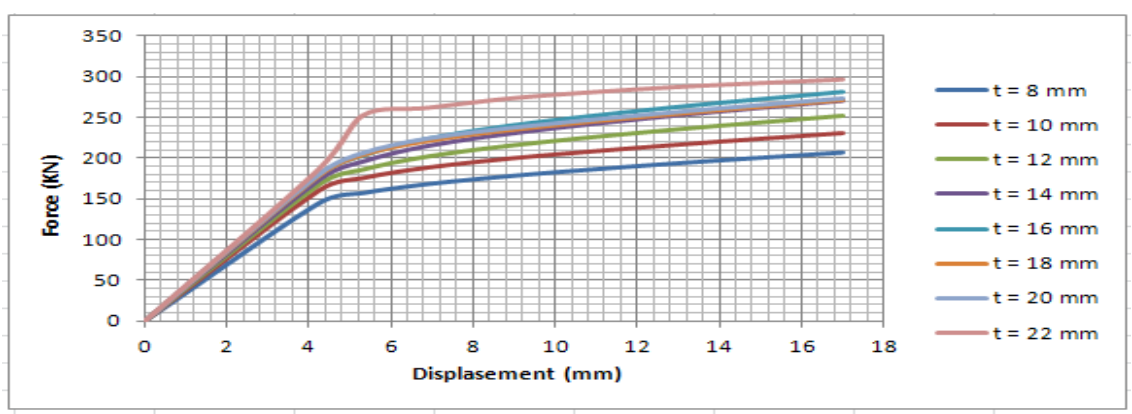


Fig 8. Force - Displacement Curves of a ring including A Radius of 220 mm and Different Thicknesses

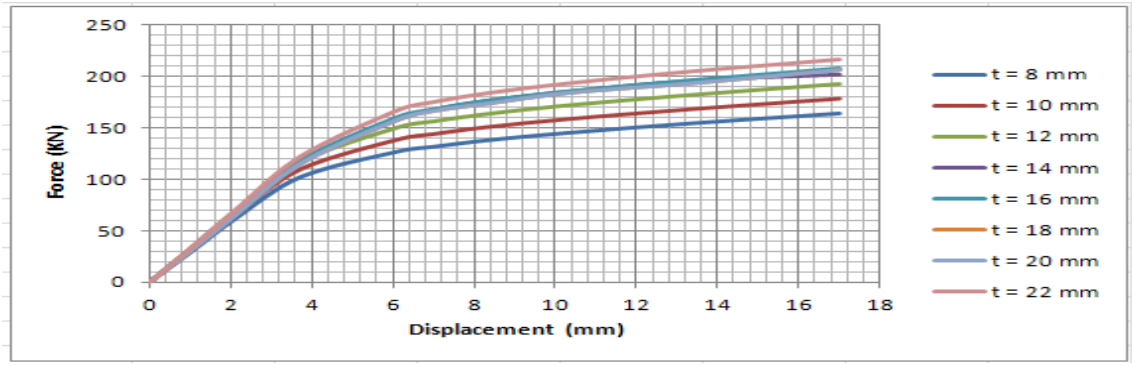


Fig 9. Force - Displacement Curves of a ring including A Radius of 250 mm and Different Thicknesses

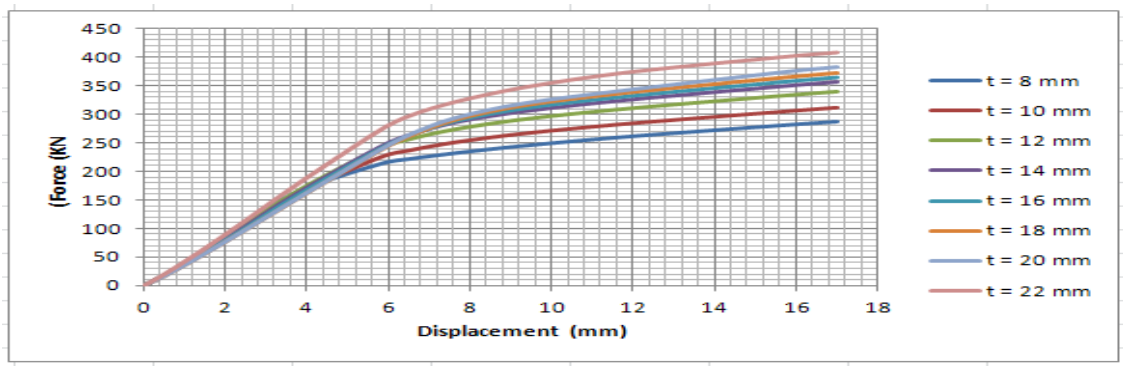


Fig 10. Force - Displacement Curves of a ring including A Radius of 150 mm and Different Thicknesses

The results show that bearing capacity increased as the thickness of the steel ring increased. A comparison of curves indicates the effect of a change in diameter on the bearing capacity. An increase in ring diameter decreased bearing capacity. The optimal conditions were when the increase in bearing capacity was accompanied by the highest ductility. Increasing the thickness and decreasing the diameter cannot increase ductility, except at the optimal thickness and diameter.

The optimal ring diameter was determined using rings with radiuses of 150, 220, and 250 mm and thickness of 12 mm during one cyclic loading (8 cycles or 16 steps in ABAQUS). This measured the effect of buckling and ductility along with energy absorption capacity. The hysteresis curve and von Misses stress contour show that the ring with a radius of 150 mm buckled during cyclic loading (6 cycles or 12 steps in 0.4 s); it could not obtain high energy absorption capacity and ductility. In the other words, it acted as do simple frames without optimization. Conversely, the ring with a radius of 220 mm showed a more effective energy absorption capacity and ductility and acceptable stiffness compared with the ring with a radius of 250 mm (Figs. 13 and 14).

As the curves and values for rings with different radiuses suggest, the bearing capacity increased as the thickness (8-18 mm) increased. The bearing capacity decreased at the 18-20 mm thicknesses relative to the 16 mm thickness. The optimized thickness was for the 8-16 mm thickness option (12 mm thickness was considered optimal). The radius was determined for an average thickness of 8 to 16 mm.

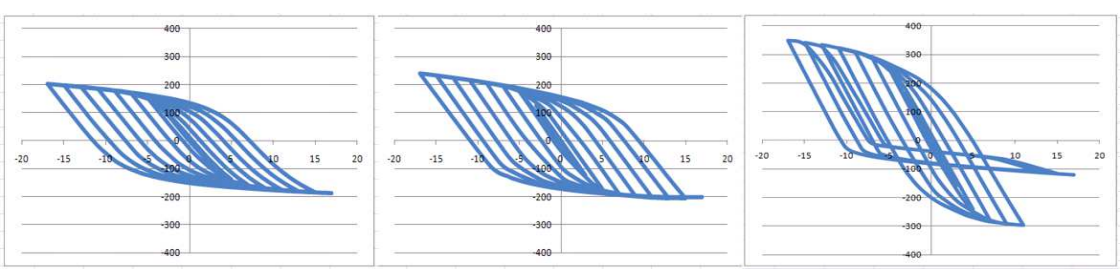


Fig 11. Hysteresis Curves of rings including 150, 220, and 250 mm radius respectively from Right to Left

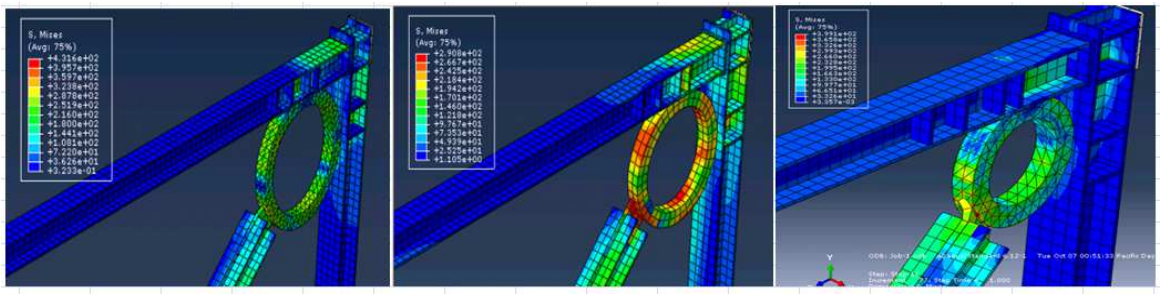
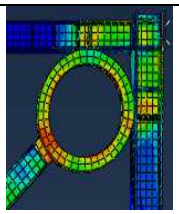
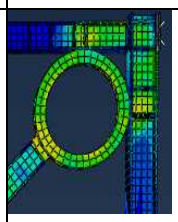
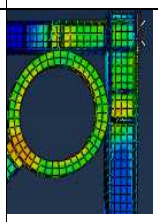
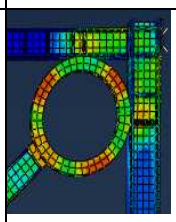
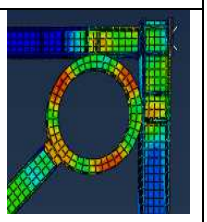


Fig 12 . Von Misses Stress Cantor of rings including 150, 220, and 250 mm radius respectively from Right to Left

The maximum von Misses stress was calculated to determine the optimal ring thickness (r = 220 mm) (Table 5). The von Misses stress decreased at >10 mm in thickness. Both the ring and some areas of the column and beam at the connection points entered into a plastic stage and their ductility decreased. The 220 mm radius, 10 mm thickness, and 50×50 mm dimensions were considered optimal for the ring.

Table 5. The Maximum Von Misses Stress of ring in Cases of Different thickness

Thickness	8	10	12	14	16
The Maximum Von Misses Stress	301.6	354.6	334.8	329	325
Color Cantor					

Conclusion

This study increased the bearing capacity and ductility of a knee brace ring as an inactive damper. The findings demonstrate that the use of this ring as an energy dissipater increased the brace system capacity and efficiency. The annular damper can dissipate a high amount of energy because it contains accurate singles and offers cyclic behavior. If its dimensions and sizes are designed accurately, it can prevent early buckling and yielding of the brace by controlling the axial force of the brace and is not immediately destroyed by the lateral bearing system. The optimal properties of an effective ring are a 220 mm radius, 10 mm thickness, and 50×50 mm in dimension.

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