A Study on Mechanical Properties of Steel Ring Dampers

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SUMMARY:
The main principles of new design methods are stiffness reduction and energy dissipation increasing. For realizing the idea, the author intends to use steel rings for concentric bracings. For this purpose, the data related to the mechanical characteristics of these elements has been extracted aiding ANSYS software. The loading procedure in computations is in accordance with ATC-24 code. Thickness, width and diameter of steel ring have been considered as the element´s dimensional variables. The mechanical properties such as initial stiffness, secondary stiffness (for simplified model), yielding deformation, yield and ultimate forces were calculated for both tension and compression modes and the results have been presented. The data will be applied in the sections of the research for simple modeling and numerical study of the structure equipped with steel ring dampers.

Keywords: steel ring, damper, bracing, energy dissipation

1. INTRODUCTION

In 2007, Abbasnia & Behkamrad commenced their on the bracing with box-shaped ductile component and applied academic tests thereon. For perceiving the element treatment inside the frame, they provided a comparison between the frame and diagonal brace and moment frame. In addition, in 2008 Messrs Abbasnia,Wetr and Kafy applied their empirical and theoretical studies on ductile steel rings. The provided tests on welded rings with the different connection plates have indicated their ductility and good performance. In 2009, Abbasnia & Mozhgani studied on the behavior of bracing including concentric rings ductile component. At the beginning of this study, two methods of concentric rings connection were studied. For each one of two rings connection methods, the element was modeled in ANSYS software. The results indicate that in the proposed model, if the larger ring is made as two half-ring, hysteresis curve will be flatten more and accordingly the energy absorption rate will be increased. In 2009, Abbasnia and Beheshti applied theoretical studies on the ring with steel plates and it was calculated whatever the thickness of connection plates is increased, the element capacity will be enhanced. As well as, they studied on the bracing with axial fuse and measured the effect of plates´ free length size on the axial fuse performance. In 2010, Abbasnia and Mohammad Hosseini accomplished their theoretical studies on the bracing with new box-shape ductile component. They observed that reinforcing the ductile component will result energy absorption and ductility.
In this study, it has been assumed that the steel ring is installed at the middle of the steel concentric braced frame. Figure 1.1 exhibits the location and installation of steel ring in the frame. Performance of the steel ring under tension and compression was studied numerically as a measure for energy dissipation.

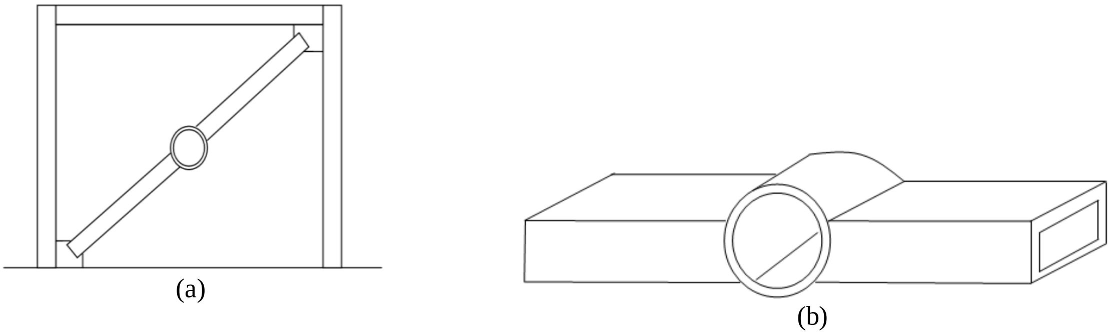


Figure 1.1. Installation and location of steel ring

Steel ring avoids the bracing buckling and in the severe earthquakes shows ductile behavior and thus causes the other frame components to remain intact.

2. CHARACTERISTICS OF MATEREALS AND STEEL RINGS DIMENSIONS

The characteristics of steel st37 used for the damper has been exhibited in figure 2.1 as the bilinear diagram. The steel parameters have been considered as $E_1 = 2 \times 10^6 \frac{kg}{cm^2}$ and $E_2 = 60000 \frac{kg}{cm^2}$ in all analyses. Yield and ultimate stresses are respectively equal to $F_y = 2400 \frac{kg}{cm^2}$ and $F_u = 3700 \frac{kg}{cm^2}$.

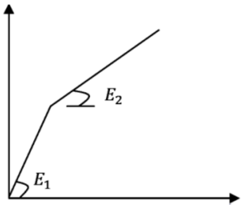


Figure 2.1. Steel bilinear diagram stress – strain

The parameters affecting the bearing capacity of steel rings such as variation of thickness (t), inside diameter (d) and width (b) were analyzed and surveyed separately. Therefore, 13 samples of steel rings were studied. The variation range of the said parameters is listed in table 2.1.

Table 2.1. The variation range of parameters of the steel ring

parameter		
t (cm)	d (cm)	b (cm)
1	20	15
1.5	30	20
2	40	25
2.5	50	30
3	60	35

The specifications of 13 respective steel rings are shown in table 2.2.

Table 2.2. Specifications of steel rings

number	Steel ring specimen
1	d20t1b15
2	d20t1.5b15
3	d20t2b15
4	d20t2.5b15
5	d20t3b15
6	d30t1b15
7	d40t1b15
8	d50t1b15
9	d60t1b15
10	d20t1b20
11	d20t1b25
12	d20t1b30
13	d20t1b35

Solid185 has been used for nonlinear static analysis of steel rings. Solid185 is used for 3-D modeling of solid structures. This element has eight nodes and three degrees of freedom at each node. Each node has a transfer degree in x, y and z directions. This element has properties including elasticity, plasticity, hyper-elasticity, stress stiffening, creep, large deflections and large strains. As well as, this element has a formulation to simulate the approximate deformations of incompressible elasto-plastic materials and fully incompressible hyper-elastic materials.

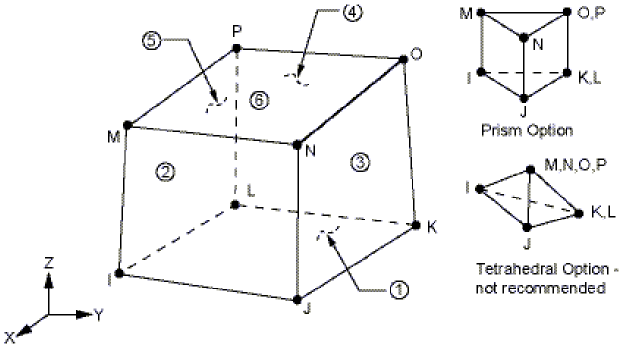


Figure 2.2. The Element of solid185

3. LOADING PROCEDURE

For loading the steel rings, ATC-24 Code is applicable. So that at first the yield displacement of each of rings was calculated by ANSYS software and accordingly the displacement diagram is on the specimens according to aforesaid Code. Loading diagram of ATC-24 Code is exhibited in figure 3.1.

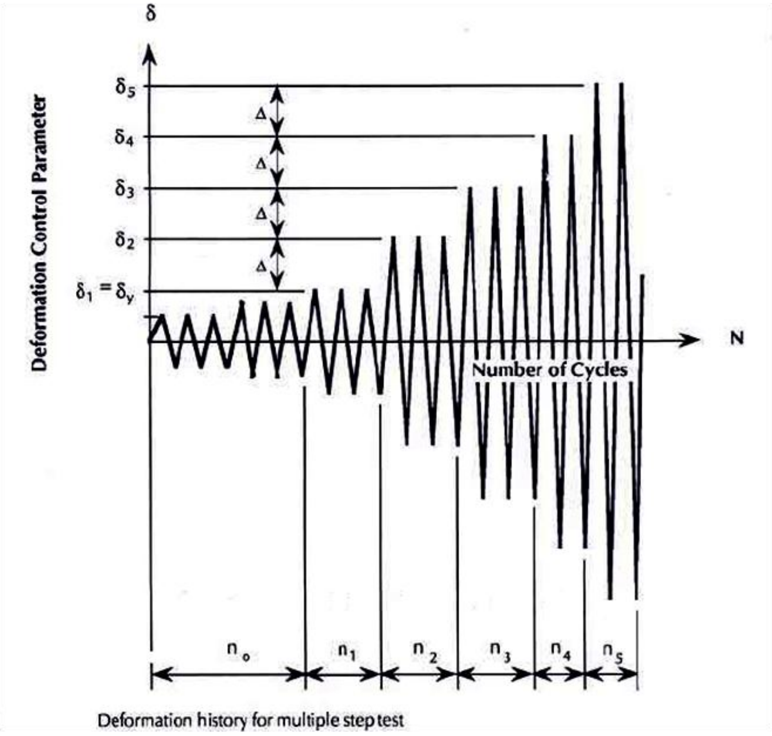


Figure 3.1. Loading diagram of ATC-24 Code

The bracing section is assumed as a box. Therefore, the ring to bracing connection area is like as a quadrangle, the loading is applied thereon. The length of each of quadrangle in figure 3.2 is equal of 10cm in all analyses.

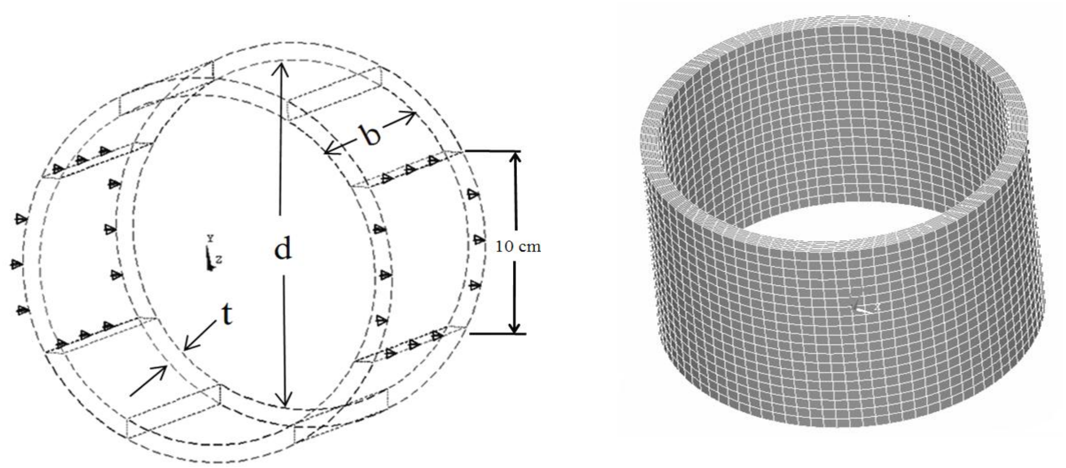
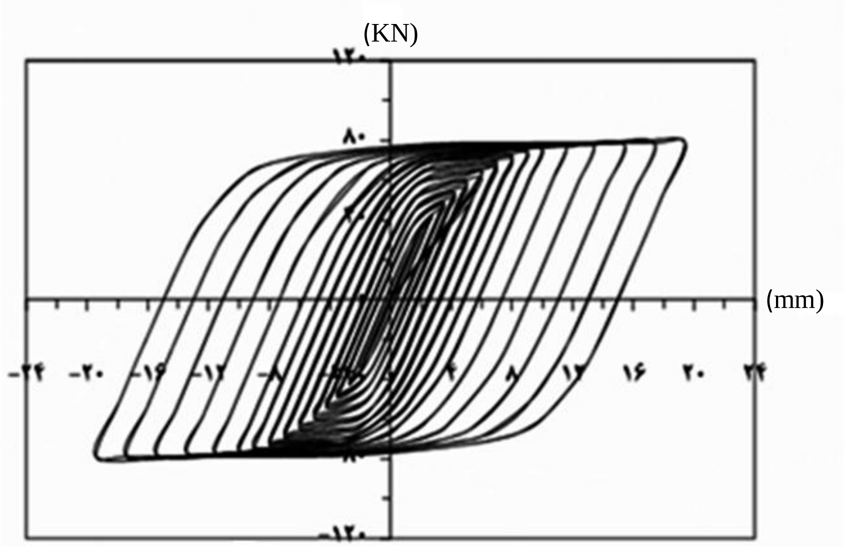


Figure 3.2. Meshing and loading location of steel ring

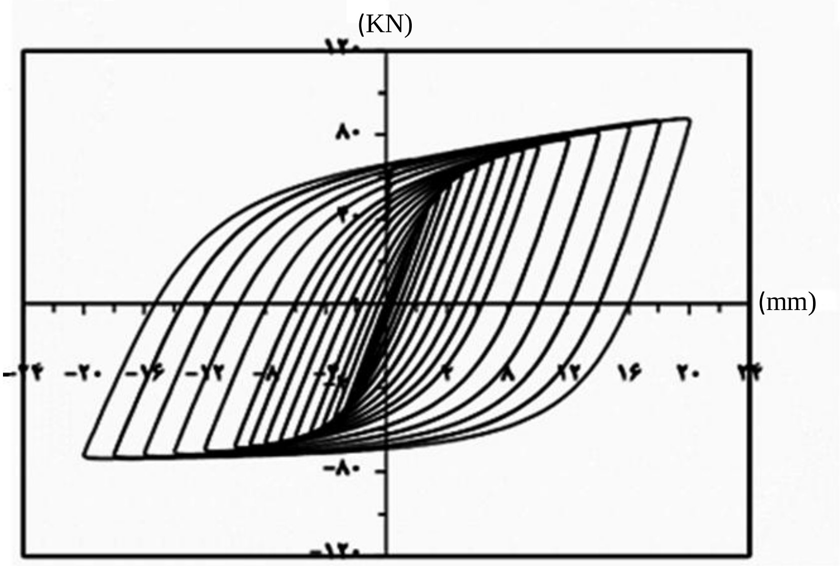
For analyzing the samples, nonlinear static analysis considering the large nonlinear geometric deformations was used.

4. CONFIRMATION OF NONLINEAR ANALYSIS OF STEEL RINGS

In order to confirm the process of steel rings analysis, the study applied by Dr.Kafy in 2008 titled "Analytical and experimental study of the effect of steel ring on ductility of concentric braces" was used. In this study, a steel ring made of CT20, 1.2cm in thickness, 10cm in internal diameter and 22cm in width was used. The steel rings including solid82 element were modeled in ANSYS software and loaded in accordance with ATC-24 Code. The bearing capacity and ultimate diameter variation of steel ring equaled to 7.89 tones and 1.96cm respectively. The experimental and analytical diagrams of steel ring have been shown in figure 4.1.



Analytical



Experimental

Figure 4.1. The analytical and experimental diagrams force – diameter variation of steel ring

In addition, in this study, the same steel ring was modeled and analyzed in ANSYS (V12) software and the same results have been obtained. The result of this study is shown in figure 4.2.

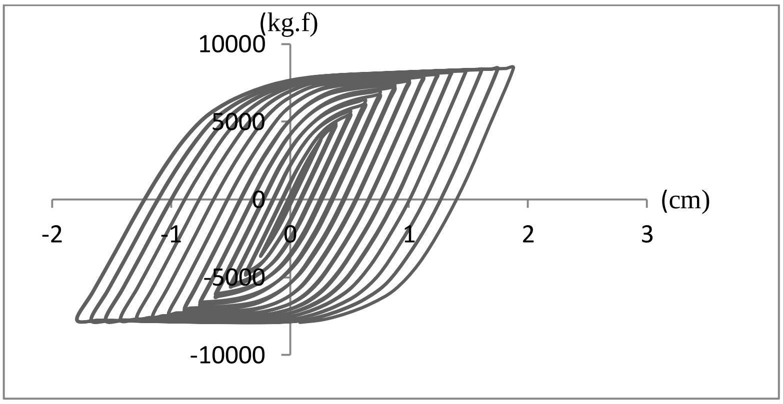


Figure 4.2. Hysteresis diagram force – diameter variation extracted from ANSYS (V12)

A sample of VON MISES stress of steel ring in ultimate stress equal to 3700 $\frac{\mathrm{kg}}{\mathrm{cm}^2}$ is show in figure 4.3. According to figure 4.3, the stress inside the ring and bracing connection area is maximum rate and this status is observed in all studied rings. Thus, the steel rings are rupture from brace connecting areas. In figure 4.3, steel ring rupture area is shown.

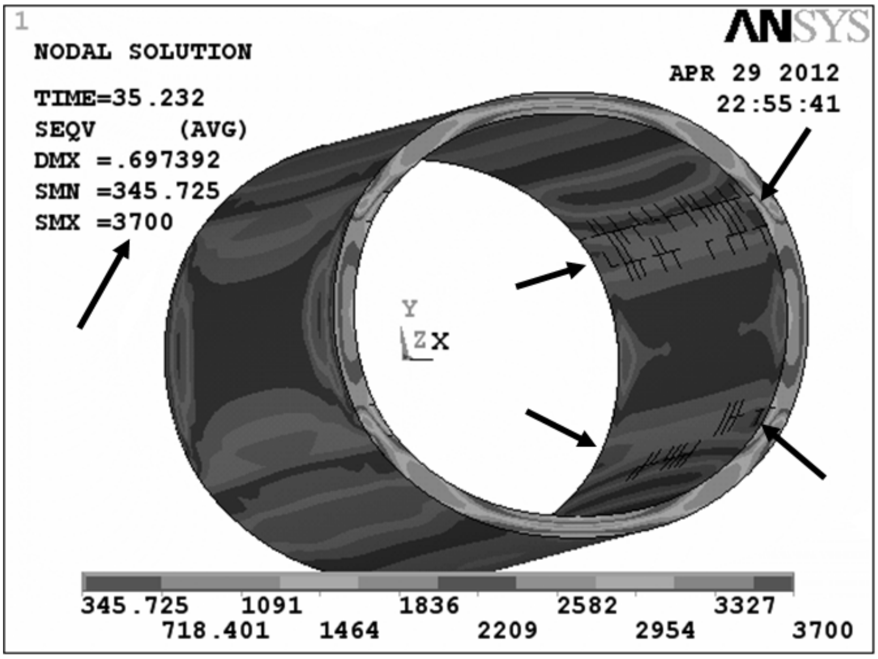


Figure 4.3. Stress maximum VON MISES and location rupture steel ring

The deformation and ultimate force of steel rings have been calculated in yield and ultimate conditions. The results are shown in tables 4.1 and 4.2.

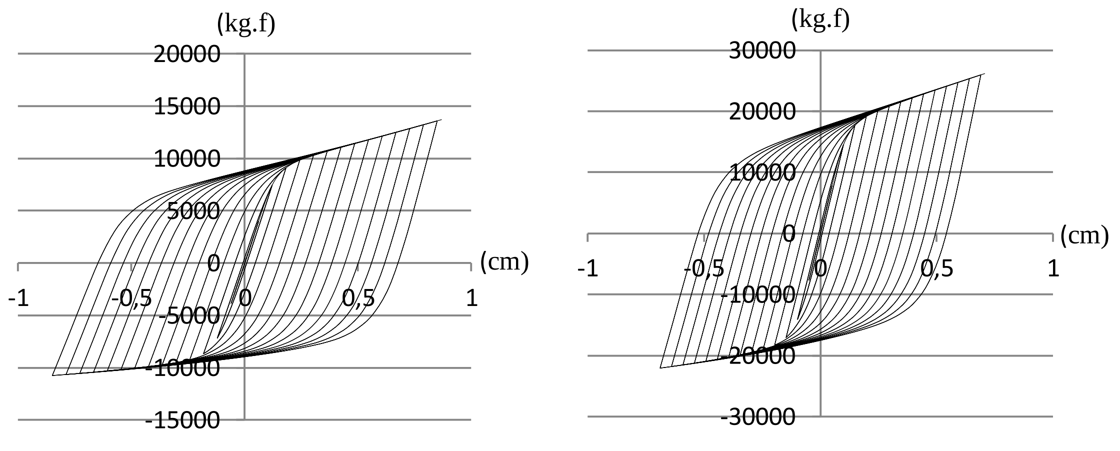
Table 4.1. The linear static analysis results

Steel ring specimen	yield tensile force (kgf)	yield compression force (kgf)	yield tensile displacement (mm)	yield compression displacement (mm)
d20t1b15	3971.9	3884.23	0.607	0.607
d20t1.5b15	7750.95	7632.69	0.492	0.492
d20t2b15	12492.7	12350.6	0.423	0.423
d20t2.5b15	17661.4	17543.4	0.373	0.374
d20t3b15	24223.5	22778.2	0.335	0.335
d30t1b15	2021.05	1973.53	1.6	1.61
d40t1b15	1477.49	1351.08	3.02	3.02
d50t1b15	2126.79	1052.38	5.35	5.05
d60t1b15	958.968	913.012	8.04	8.06
d20t1b20	5176.54	5170.82	0.627	0.641
d20t1b25	6266.73	6255.48	0.629	0.644
d20t1b30	7446.6	7344.08	0.638	0.646
d20t1b35	8510.87	15836	0.636	0.647

Table 4.2. The nonlinear static analysis results

Steel ring specimen	Ultimate tensile force (kgf)	Ultimate compression force (kgf)	Ultimate tensile displacement (mm)	Ultimate compression displacement (mm)
d20t1b15	13705.9	10754.1	8.68	8.49
d20t1.5b15	26166.4	22065.1	7.0609	6.89
d20t2b15	41112.16	36226.2	6.0552	5.85
d20t2.5b15	57397.41	52552.5	5.238	5.2
d20t3b15	75294	70110.2	4.7586	4.62
d30t1b15	7026.6	5473.24	19.634	18.6
d40t1b15	4944.26	3687.84	36.444	34.6
d50t1b15	3704.79	2699.04	53.022	48.4
d60t1b15	2957.22	2114.69	71.261	64.6
d20t1b20	17717.1	13999.9	8.444	8.35
d20t1b25	21769.8	17207.3	8.378	8.28
d20t1b30	25998.1	20399.7	8.5102	8.31
d20t1b35	30011.4	23571.8	8.445	8.33

For instance, two force hysteresis-diameter variation diagrams of steel ring have been shown in figure 4.4.



d20t1b15

d20t1.5b15

Figure 4.4. Hysteresis diagrams force – diameter variation of the steel ring

Hysteresis diagrams indicate that the steel ring can be used as an appropriate ductile component for the concentric braced frame. According to the results of analysis, the variation of each of the parameters in proportions to the ultimate bearing capacity of steel rings can be drawn.

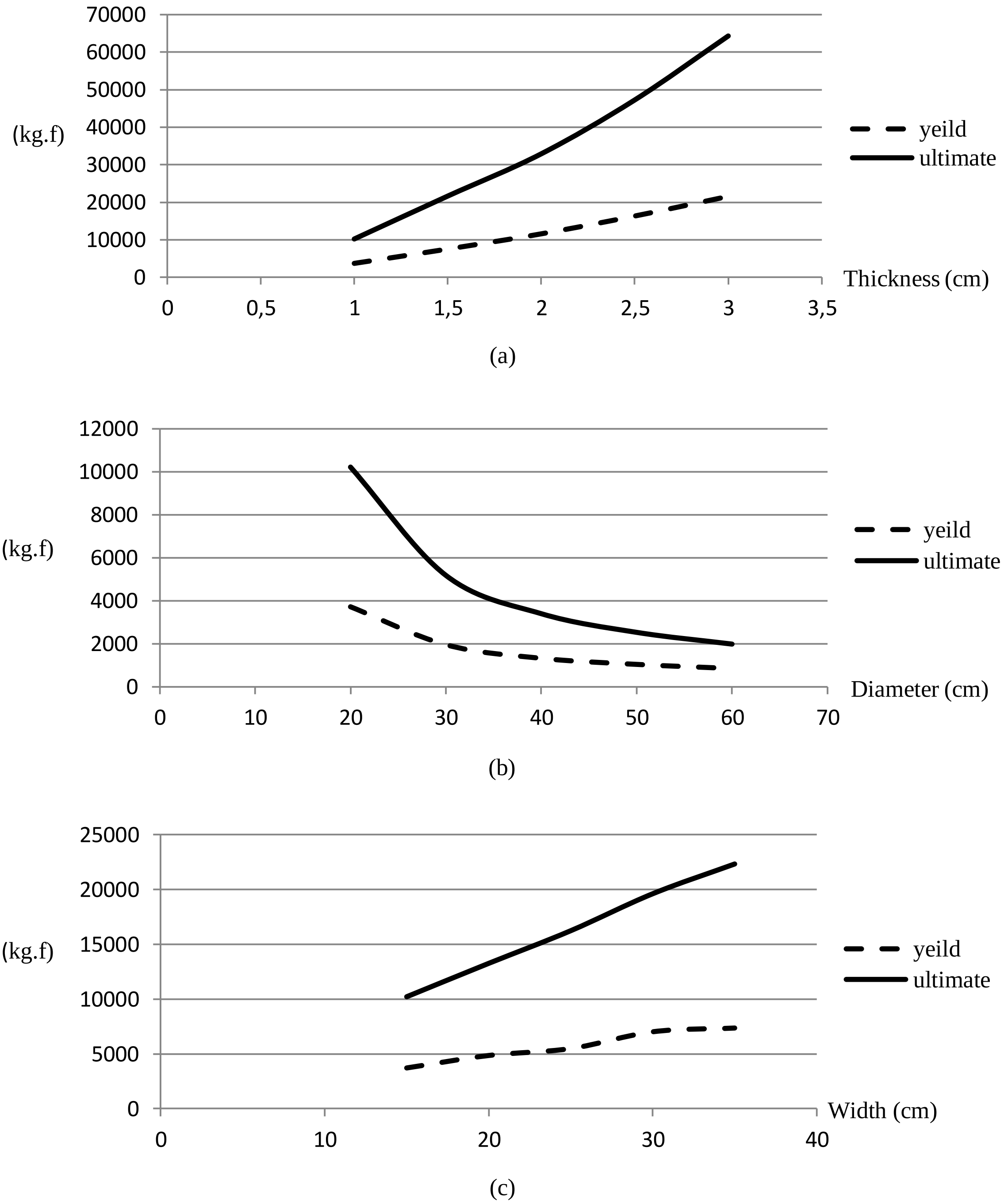


Figure 4.5. Diagrams force – parameter steel rings

According to the above diagrams, upon increasing the ring thickness and width, and reducing the inside diameter, the bearing capacity of steel ring in increased.

5. CONCLUSIONS

According to the obtained results, steel ring can be used as the fuse in concentric braced frame. All rings are rupture from the inside in their ultimate capacity. The ultimate capacity of the rings has direct relationship with ring width and diameter and inverse relationship with the ring thickness. The ultimate capacity of the rings under compression is slightly lower than ultimate capacity in the tensile condition.

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