

## Behavior of Rubberized Concrete-Filled Square Steel Tube Under Axial Loading

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© 2019 جامعة العلوم والتكنولوجيا، اليمن. يمكن إعادة استخدام المادة المنشورة حسب رخصة مؤسسة المشاع الإبداعي شريطة الاستشهاد بالمتألف والمجلة.

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### Abstract

The purpose of this paper is to investigate the behavior of rubberized concrete-filled steel tube (RuCFST) analytically by using ABAQUS 6.12 -1 software for square columns under axial loading. Twelve specimens modeled with various variables which are rubber content as replacement percentage from natural aggregate (0%, 5% and 15%), tube thickness (3mm and 6mm) and columns' length (1.5m and 3.0m). The results showed an adoption model of RuCFST columns subjected to axial force in elastic and plastic properties of steel and concrete gives a good agreement between numerical and references experimental results. Also, the results showed a reduction in column capacity with increasing rubber content. In contrast, the results showed an increase in the columns' compression capacity with increasing the thickness from 3 to 6mm. In addition, columns' lengths have no significant effect on compression capacity, although the corresponding shortening increased with increase column's length.

**Keywords:** Rubberized concrete, Infilled steel tube, Finite element, Axial loading and ABAQUS.

## سلوك الأنابيب المعدنية المملوءة بخرسانة مضاف إليها مفروم إطارات المركبات تحت التحميل الرأسي

### الخلاصة:

الغرض الرئيسي للدراسة الحالية هو دراسة سلوك الأعمدة المعدنية المملوءة بخرسانة مصنعة من إطارات المركبات (RuCFST) عن طريق التحليل الرقمي باستخدام برنامج الأبيكوس 1 - 6.12 للأعمدة مربعة الشكل تحت التحميل الرأسي. تم نمذجة إثنا عشر عينة تحمل العديد من المتغيرات والتي تشمل نسبة محتوى المطاط كنسبة بديلة عن الركام الطبيعي بنسب (0% و 5% و 15%)، وسماكة الإطار المعدني (3م و 6م) وأيضاً طول العمود (1.5م و 3.0م). أظهرت النتائج أن النموذج الرقمي المتبنى للأعمدة الـ RuCFST والمعرضة لحمل رأسي أعطى توافق كبيرين بالمقارنة مع النتائج العملية في مرحلة المرونة ومرحلة اللدونة للإطار المعدني وكذلك الخرسانة. كما أظهرت النتائج أيضاً تناقصاً في قدرة تحمل الأعمدة مع زيادة محتوى المطاط. على العكس، أظهرت النتائج تزايد في سعة تحمل الأعمدة مع زيادة سماكة الإطار المعدني من 3م إلى 6م. أثبتت النتائج أيضاً أن طول الأعمدة ليس له تأثير جوهري على سعة تحملها، كما أن التشوه المقابل للقوى القصوى ازداد بازدياد طول العمود.

الكلمات المفتاحية: الخرسانة المصنعة من إطارات المركبات، الإطارات المعدنية المملوءة، العناصر المحدودة، التحميل الرأسي، برنامج الأبيكوس.

## 1.Introduction:

Overall the world, every year number of waste tyers have increased. In these days more than one billion tire have reached the end of their useful lives and this number is increasing every year and it is expected to reach 1.5 billion by 2030 [1]. Moreover, about 3.5 million tons of tires reach out of service in Euro countries alone [2].

The demand for recycling waste tire comes from several reasons. First reason, the west tires are solid waste are non-disintegration material, which make this problem accumulated. Moreover, the bulk size of the tire is a void, which increased the required landfilling spaces. Also these voids consider an adequate environmental for rodents. On the other hand, recycling of waste tiresconserve the natural resources.

Precedent studies which focus on the behavior of rubberized concrete (RuC) showed that using rubber as partial replacement in concrete reduce the compression and tension behavior gradually with increase rubber content. Meanwhile, the density, modulus of elasticity and workability decrease gradually with increasing crumb rubber percentage [36-]. In contrast, using rubber in concrete enhance the ductility, impact resistance, energy dissipation and damping ratio [7,8,4].

Moreover, using rubber in concrete lead to decrease columns compression capacity and modulus of elasticity while the lateral deformation increases before buckling failure occur[9]. On the other hand, columns which are subjected to lateral load, the energy dissipation and hysteretic damping ratio increased whereas viscous damping ratio decreased. Moreover, using rubber has marginal influence on column ultimate lateral strength [10].

Regarding RuCFST subjected to axial loading. The compression capacity of columns decreases with increase rubber content[11,12]. On the other hand, RuCFST which subjected to lateral loads (monotonic and cyclic), the increasing of rubber content has no significant losses on columns behavior under monotonic loading [13,14], and some degradation effects for columns under cyclic loading [14].

Overall, we notice that all previous study focuses on the short columns; so it's necessary to investigate slender columns in order to get a perfect understanding for the behavior of rubberized concrete-filled steel tube (RuCFST) columns. Because column's slenderness has a considerable impact

in columns behavior including the capacity, the failure pattern, etc., this paper study this effect beside different variables to identify the effect of columns' slenderness with each variable. Moreover, this study widens the range of the previous studies by investigate different columns' dimension and different tube thicknesses.

## 2. Description of Numerical Models:

In this section, the experimental program will be explained and models verification will be investigated according to Duarte, et al. study [12]. Moreover, the columns' numerical models are described including the geometry, material properties and modeling steps.

### 2.1 References Experimental Program:

Duarte, et al. [12] tested forty-two composite filled steel tube (CFST) for short columns after 28 days with three rubber replacement percentage (0%, 5% and 15%), three steel grades, three columns' shapes, and two thicknesses under axial loading by using test equipment which is presented in Figure1[12]. Beside some of Duarte, et al. parameters, the new parameter which is added to this paper is column length.

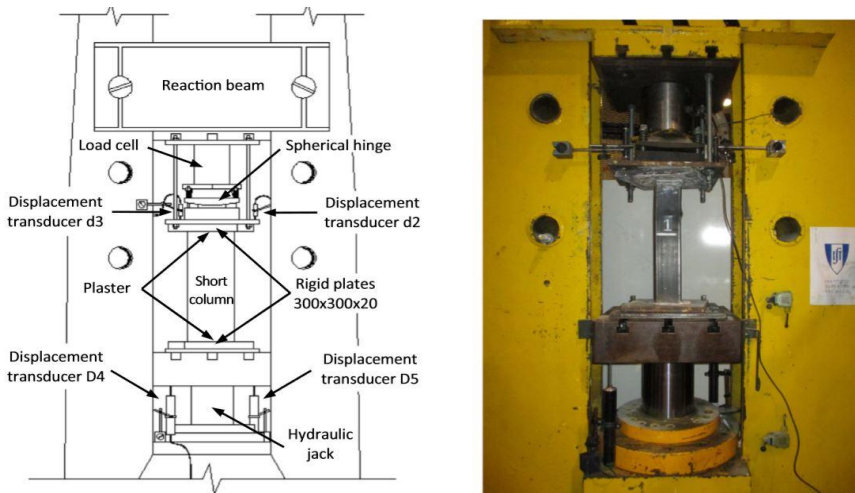


Figure (1): Test Equipment [12]

## 2.2 Numerical Program:

### 2.2.1 Research Parameters:

Twelve square specimens simulated with various variables which are three rubber replacement percentages (0%, 5% and 15%), two slenderness ratio  $b/t$  ( $t=3$  compact and  $t=6$ mm slender) and two lengths of the column ( $SH=1.5$ m and  $L=3.0$ m). Table 1 presents the specimens properties and dimensions.

**Table (1): Specimens**

Specimen ID	Height (m)	Thickness (mm)	Depth x width (mm)	Ru%
S200x3-SH-Ru0%	1.5	3	200X200	0
S200x3-SH-Ru5%	1.5	3	200X200	5
S200x3-SH-Ru15%	1.5	3	200X200	15
S200x3-L- Ru0%	3.0	3	200X200	0
S200x3-L- Ru5%	3.0	3	200X200	5
S200x3-L- Ru15%	3.0	3	200X200	15
S200x6-SH- Ru0%	1.5	6	200X200	0
S200x6-SH- Ru5%	1.5	6	200X200	5
S200x6-SH- Ru15%	1.5	6	200X200	15
S200x6-L- Ru0%	3.0	6	200X200	0
S200x6-L- Ru5%	3.0	6	200X200	5
S200x6-L- Ru15%	3.0	6	200X200	15

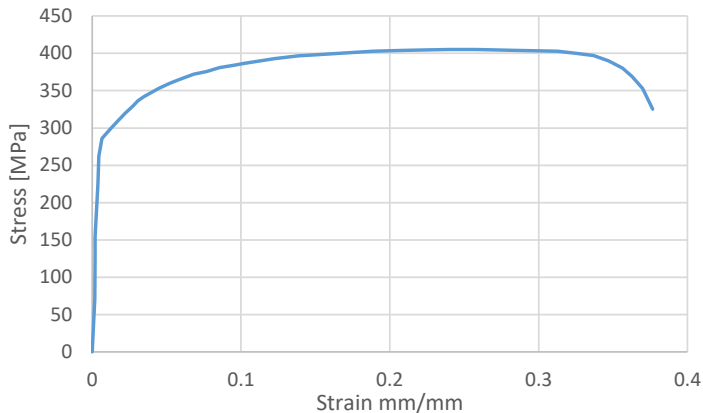
Depend on AISC classification Table2 [15], two width-to-thicknesses ratio ( $b/t$ ) chose to reach compact and slender section  $t=3$ mm and  $t=6$ mm respectively.

**Table (2): Limiting Width-to-Thickness Ratio for Compression Steel Element in Composite Members Subjected to Axial Compression. ANSI/AISC 360-10 [15]**

Description of Element	Width-to-Thickness Ratio	$\lambda_p$ Compact/ Noncompact	$\lambda_r$ Noncompact/ Slender	Maximum Permitted
Wall of Rectangular HSS and Boxes of Uniform Thickness	$b/t$	$2.26 \sqrt{\frac{E}{F_y}}$	$3.00 \sqrt{\frac{E}{F_y}}$	$5.00 \sqrt{\frac{E}{F_y}}$
Round HSS	$D/t$	$0.15E/F_y$	$0.19E/F_y$	$0.31E/F_y$

## 2.2.2 Material Properties:

Cold formed with Grade 235 in according with EN 10219- 2 [16] specification simulated as 3D shell deformable part. Mechanical properties of the steel (yield strength  $f_y$ , ultimate strength  $f_u$ , modulus of elasticity with yield strength  $E_s$  and Poisson's ratio  $V_s$  is shown in Table 3. The standard value for Poisson's ratio 0.3 used. Additionally, Figure 3 [12] exhibit stress-strain curve for the steel tube Grade 235.



Figure(3): Stress-Strain Curve for Steel Grade 235 [12]

Table(3): Mechanical Properties of Steel Tube [12]

Steel Grade	Fy (MPa)	Fu (MPa)	Es (GPa)	vs
S235	284	403	200	0.3

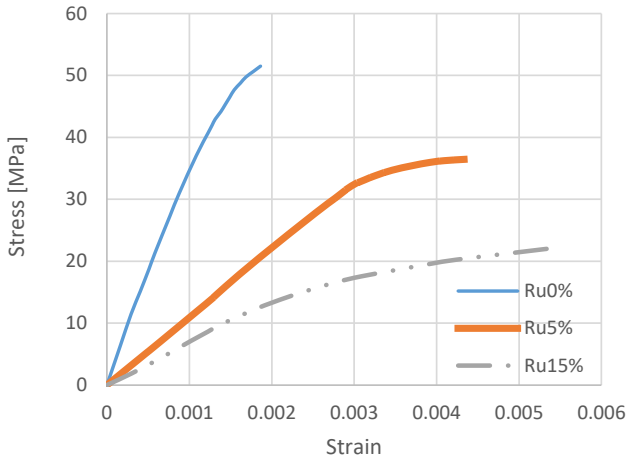
For the concrete, the experimental mechanical properties of concrete cubes (cube compression strength  $f_{cu}$ , splitting tension strength  $f_{ct}$ , modulus of elasticity  $E_c$ , elastic strain gauge value  $\epsilon$  and Poisson's ratio  $\nu$ ) of the three-rubber replacement percentage Ru0%, Ru5% and Ru15% are presented in Table4. Also, experimental Stress-Strain curves of the three rubber replacement ratios are presented in Figure4 [12]. The Poisson's ratio of Ru0% assumed 0.2. However, the Poisson's ratio of rubberized concrete calculated by using rule of mixtures [18].

$$v_{RuC} = v_{NC}V_{concrete} + v_{Ru}V_{rubber} \quad (1)$$

where  $v_{RuC}$  is Poisson's ratio of RuC,  $V_{concrete}$  and  $V_{rubber}$  are the volumetric fraction of concrete matrix and rubber particles in the RuC mixes [12] respectively and  $v_{Ru}$  the Poisson's ratio of the rubber particles ( $v_{Ru}=0.50$ ) [19].

**Table (4): Mechanical Properties of The Concrete Mixes [12]**

Concrete ID	$f_{cu}$ (MPa)	$E_{cu}$ (GPa)	$F_{cut}$ (MPa)	$\epsilon_{cu}$	$\nu$
Ru0%	49.5	37.6	3.4	0.2	0.2
Ru5%	39.3	33.4	2.6	0.42	0.21
Ru15%	25.2	25.2	2.0	0.54	0.23

**Figure (4): Compressive Stress-Strain Curve for Ru0%, Ru5% and Ru15% [12]**

The plastic behavior of concrete modelled in ABAQUS [17] by using concrete damage plasticity (CDP), based on Drucker-Prager Hyperbolic Function. The CDP parameters which used in simulation present in Table 5. Meanwhile, depend on experimental results, the compression behavior defined in CDP model by using equation 2- equation 5 with reduction factor equal 0.4 when the strain equal 0.01 [16]. On the other hand, tension behavior in CDP took as the experimentally value of splitting tensile strength  $f_{cutm}$ , which presented in Table4, linearly to zero with cracking strain from zero to fully opened crack 0.08mm.

$$\sigma = f_{cm.cyl} \frac{k\eta - \eta^2}{1 + (k - 2)\eta} \quad (2)$$

Where:

$$\eta = \frac{\epsilon}{\epsilon_{cu}} \quad (3)$$

$$k = 1.05 E_{cm} \frac{\epsilon_c}{f_{cm.cyl}} \quad (4)$$

$$f_{cm.cyl} = (0.76 + .2 \log_{10} \frac{f_{cm}}{19.6}) f_{cm} \quad (5)$$

**Table (5): The Parameters of Concrete Damaged Plasticity CDP**

Concrete Type	Dilatation Angle	Eccentricity	$\sigma_{b0}/\sigma_{c0}$	K	Viscosity Parameter
NC	15	0.1	1.16	0.67	0.0002
Ru5%	7.5	0.1	1.16	0.67	0.0002
Ru15%	5	0.1	1.16	0.67	0.0002

### 2.2.3 Loading and Boundary Conditions:

The axial loading applied as displacement on the top plates along Y axis towered the bottom plate. The references point of the top plates were restrained against two displacement transition along X and Z axis, and the three rotational (X, Y and Z). meanwhile, the reference point of the bottom plate restrained against all displacement and all rotational transitions along X, Z and Y axis.

The contact interface between the column's ends and the plates, top and bottom, is tie which means there are not any relative motion between the plates and column's ends. The normal behavior is hard contact [17] between steel tube and concrete core with allow separation after contact. The friction coefficient in tangential behavior [17] is 0.25.

### 2.2.4 Mesh:

Regarding the concrete core, 5040 elements for short column and 10080 elements for long column with 8 nodes solid three dimension with full integration (C3D8) used in ABAQUS [17]. Although, the steel tube modeled as shell by using 4-node doubly curved shell with reduced integration (S4R) in numerical modeling, with mesh equal 2160 and 4320 elements for short column and long column respectively. Figure5 presents mesh of composite element, concrete core and steel tube.

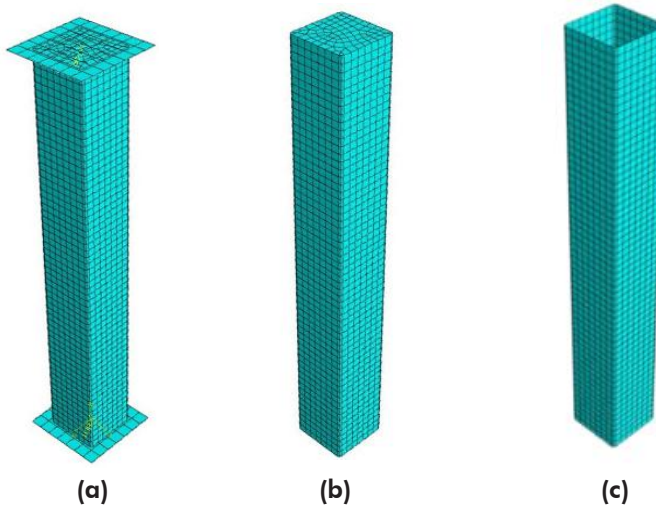
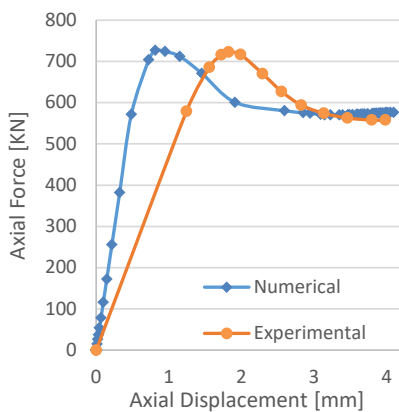


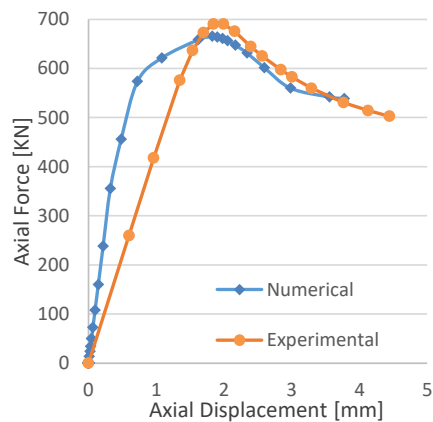
Figure (5): Mesh of Specimens a) Composite Element, b) Concrete Core and c) Steel Tube

### 3. Model Verification:

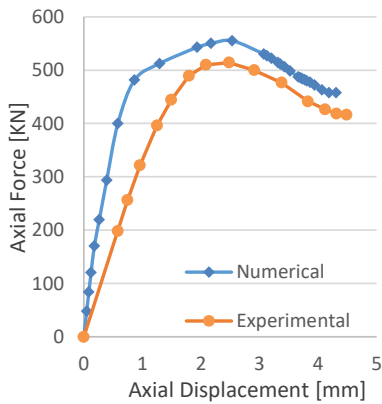
In order to ensure the simulation results are realistic, the results compared with references experimental study [12]. Figures 6a,b,c present the results of numerical simulation for CFST-Ru0%, 5% and 15% subjected to axial loading by compare them with reference experimental results [12]. Moreover, Figure 6-d, compare between experimental and numerical FEM analysis deformation's failure mode for Ru0CFST column.



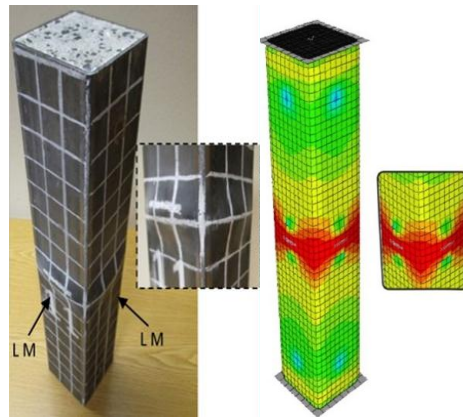
(a) P-u Curves of Ru0%CFST



(b) P-U Curves of Ru5%CFST



(c) P-u Curves of Ru5%CFST

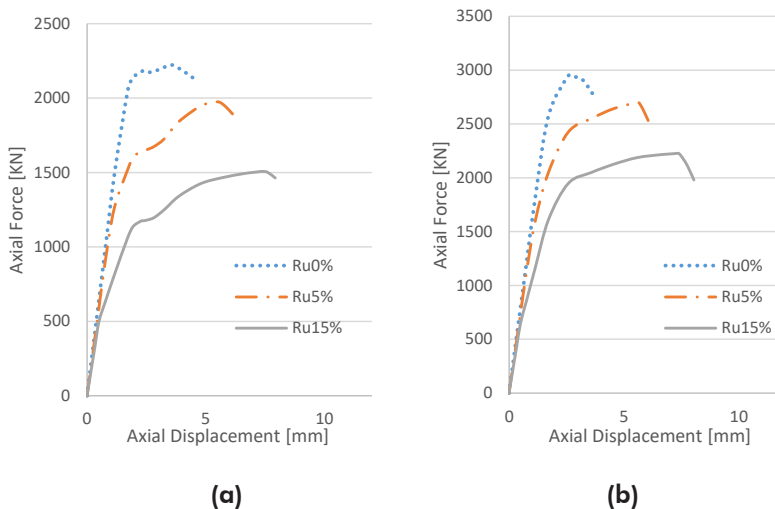


(d) Failure Mode for Ru0%

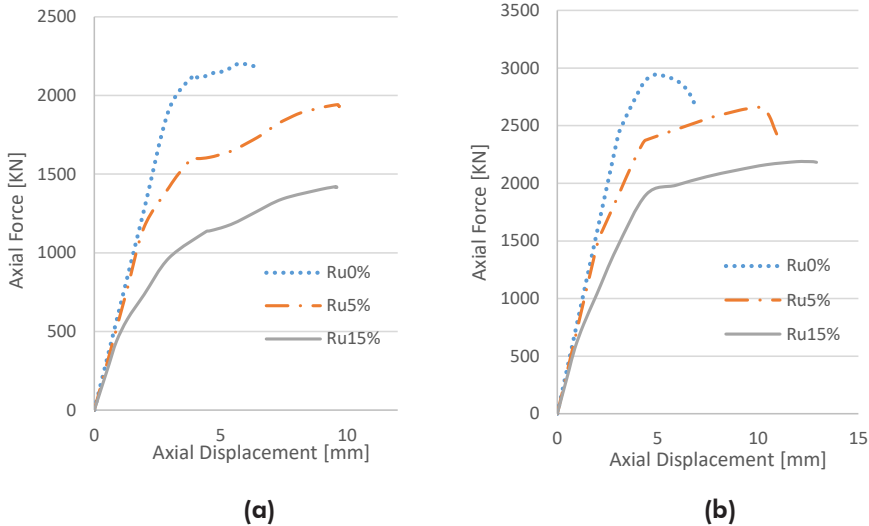
**Figure6: Numerical vs. Experimental Results [12] of S100x100x 3 Columns :Under Axial Loading**

#### 4.Results of Numerical Simulation

In this section, the results of numerical model are presented. Also, the effect of each parameter on columns' behavior will recognize. Figures 7 and 8 present P-u Curves, Axial Load vs. Axial Displacement, for each column with the three rubber replacement ratios in each chart, Ru0%, Ru5% and Ru15%.



**Figure(7): P-U Curve of Numerical Simulation for Short Columns Under Axial Loading. a) S200x3-SH and b) S200x6-SH**



**Figure(8): P-U Curve of Numerical Simulation for Long Columns Under Axial Loading a) S200x3-L and b) S200x6-L**

#### 4.1 Influence of Rubber Content

In order to investigate the effect of rubber content in columns behavior that subjected to axial load, Table 6 shows the maximum compression capacity at each rubber content, the ratio between maximum force for the specimen and reference specimen, and axial shortening. Rubber replacement percentage has clearly influence on compression capacity and behavior of the columns. As same as most previous studies [11,12], the column's compression capacity decrease with increase rubber replacement percentage as shown in Figures 8 and 9. However columns' length shows no noticeable impact on column behavior under axial loading.

**Table (6): Effect of Rubber Particles on Column Behavior Under Axial Loading**

Group	Specimen ID	Pmax	Pmax/Pmax-Ru0%	umax
1	S200x3-SH-Ru0%	2222.87	-	3.57
	S200x3-SH-Ru5%	1973.95	0.89	5.41
	S200x3-SH-Ru15%	1507.39	0.68	7.40
2	S200x6-SH-Ru0%	2948.27	-	2.58
	S200x6-SH-Ru5%	2700.56	0.92	5.58
	S200x6-SH-Ru15%	2227.17	0.76	7.35
3	S200x3-L-Ru0%	2202.73	-	5.74
	S200x3-L-Ru5%	1941.56	0.88	9.62
	S200x3-L-Ru15%	1419.95	0.64	9.52
4	S200x6-L-Ru0%	2946.46	-	4.96
	S200x6-L-Ru5%	2659.94	0.90	7.64
	S200x6-L-Ru15%	2188.94	0.74	11.93

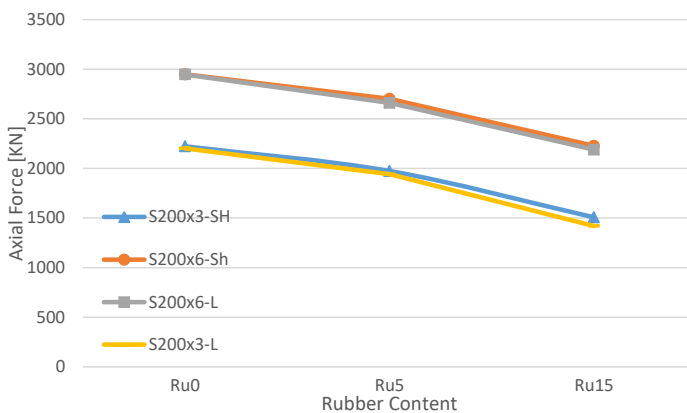
For short-slender specimens (group-1), columns' compression capacity decreased 11% and 32% for Ru5% and Ru15% respectively compared to Ru0%. Although, long-slender specimens (group-3) showed close results to group-1 with decrease equal 12% and 36% in compression capacity for Ru5% and Ru15% respectively. However, short and long compact specimens (group-2 and 4) respectively showed less decrease in columns' compression capacity than group-1 and 3, with reduce equal 8% and 14% for group-2 and 10% and 16% for group-4 for Ru5% and Ru15% respectively. On the other hand, corresponding shortening increase gradually with increase rubber replacement percentage.

## 4.2 Influence of Tube Thickness

Thickness of the tube has remarkable influence into column behavior. The column strength increases with increase column thickness. For example, short columns capacity increased with increasing thickness from 3mm to 6mm by 33%, 37% and 48% for Ru0%, Ru5% and Ru15% respectively. However, long columns increased by 34%, 37% and 54% for Ru0%, Ru5% and Ru15% respectively. As result, columns' compression capacities have higher increasing with increase rubber replacement percentage.

### 4.3 Influence of Length of The Column

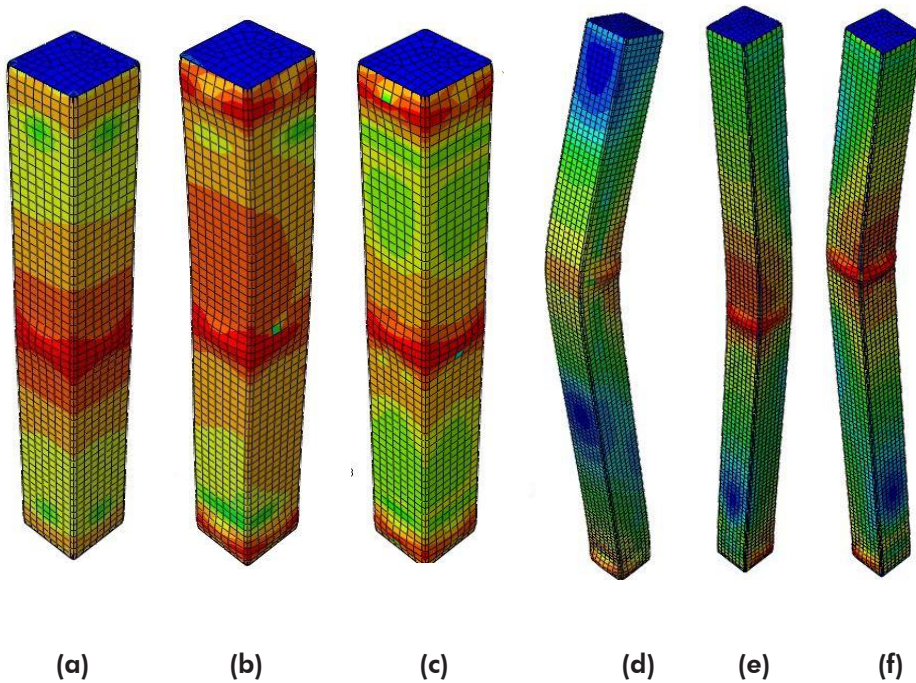
As shown in Figure 9, the columns showed no significant effect on column compression capacity when the thickness increase from 3mm to 6mm, neither for column with 3mm thickness nor 6mm. Regarding axial displacement, the corresponding shortening increased with increase column's length. For columns with 3mm thickness the corresponding shortening increased 61%, 78% and 29% for Ru0%, Ru5% and Ru15% respectively, whereas the increasing for columns with 6mm thickness was 92%, 37% and 62% for Ru0%, Ru5% and Ru15% respectively.



**Figure(9): Influence of Rubber Replacement Percentage on The Columns Behavior**

### 4.4 Failure Modes:

All of short column fail due to concrete crush and the local mechanism developed until yielding and buckling in steel tube as shown in Figures 10a, b, c. This type of failure, local buckling, often occurs at multiple locations over the column's length. Alternatively, the long columns fail due to global buckling, the column bends at one position often near mid-height as shown in Figures 10d,e,f. These results obtained in all rubber replacement percentages Ru0%, Ru5% and Ru15%.



**Figure 10: Columns' Failure Modes**

a) R300x6-A-SH-Ru0, b) R300x6-A-SH-Ru5, c) R300x6-A-SH-Ru15, d) R300x6-A-L-Ru0, e) R300x6-A-L-Ru5, f) R300x6-A-L-Ru15

## 5. Conclusions

In this study, composite column filled with rubber concrete RuCFST in different rubber replacement percentage from natural aggregate with different steel tube thicknesses and column's lengths were investigated. First, short introduction with literature review were presented. Then the models were described and simulated by using ABAQUS [17] after models verification have done depend on Duarte, et al. study [12]. Finally, the numerical results were presented, discussed and compared with the references specimens. The main conclusions of the study are:

- The approved model of columns subjected to axial force in elastic and plastic properties for steel and concrete gives a good agreement between numerical and experimental results.
- The compression capacity of the columns decreases with increase rubber replacement ratio up to 12% for S200x3-L-Ru5% and 36% for S200x6-L-Ru15% in compare with references specimens Ru0%. These results conform with previous studies [3-6].

- Corresponding shortening with maximum force increase with increase rubber replacement percentage up to 3.88mm for S200x3-L-Ru5% and 6.97mm for S200x6-L-Ru15% in compare with references specimens Ru0%.
- Column's compression capacity increase with increase the tube thickness. In short columns, the capacity increased by increasing thickness from 3mm to 6mm by 33%, 37% and 48% for Ru0%, Ru5% and Ru15% respectively. Although, the long column increased by ratio 34, 37 and 54% for Ru0%, Ru5% and Ru15% respectively.
- Column's length has no significant effect on column's compression capacity.
- Corresponding shortening with maximum force increased with increase column's length, the increasing for columns with 3mm tube thickness was 61, 78 and 29% for Ru0%, Ru5% and Ru15% respectively. However, the increasing for 6mm tube thickness was 92, 37 and 62% for Ru0%, Ru5% and Ru15% respectively.

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