Analysis of Recycled Aggregate Concrete Filled Steel Tube (CFST) under Different Loading Conditions

Gajendra Singh[1], S P Sharma[2], B S Tyagi[3]

[1]*Master of Technology, Radha Govind Group of Institution, Meerut, India*
[2]*Asst. Professor, Civil Engineering KIET College Ghaziabad, India*
[3]Professor, *Radha Govind Group of Institution, Meerut, India*

---***---

Abstract - *Concrete filled steel Tubes (CFST) were used from the early 1900s in the construction. However, detail research over the CFST did not begin until 1960. After that a numerous studies on CFST were conducted to completely understand their behaviour with the objective of improving their performance.* ***This research paper addresses an experimental study to find out the effect of some of the major factors influencing the compression behaviour of tubular circular columns filled with recycled aggregate concrete (RACFST)****. The Recycled Aggregate (RA) can come from the destruction of buildings, bridge, airport runways and concrete floors. Concrete made with such aggregate is said to be recycled aggregate concrete (RAC). The parameters of concern are mainly the compressive strength of the concrete, the diameter-to-thickness ratio of the steel pipes and the loading rate. The test program includes two grades of concrete made by the recycled aggregate of* ***compressive strength of 30 MPa and 40 MPa*** *and three* ***diameter to thickness ratios of 25.283, 32.598 and 38.948.*** *A nonlinear numerical finite element (FE) model using the Abaqus finite element modelling software. It is also developed and verified using the proposed experimental results. It was found that the effect of the relationship on the compression behaviour of the CFST column is greater than the effect of the other factors. Furthermore, the stiffness of CFST specimens is strongly influenced by the ratio to the influence of the compressive strength of the concrete filling or the loading rate.*

Key Words**: Concrete-Filled Steel Tube (CFST), Recycled aggregate concrete-filled steel tube (RACFST), Recycled aggregate concrete (RAC), Finite element (FE), External Diameter to the thickness of Steel tube (D/t)**

1. INTRODUCTION

Nowadays, steel tube columns filled with cement concrete are used in construction at a large scale. In fact, such type of structural elements are good in practice because of its less cross-section with respect to the load bearing capacity ratio. Therefore, the maximum concrete columns in the lower floors of high rise buildings can be replaced by smaller sections of the CFSTs columns. Furthermore, CFST elements is generally used as pillars of bridges in congested areas, and also the continuous industrial development creates a serious issue of discharge of construction and demolition waste. But, there is the problem of the scarcity of natural aggregates (NA) for the production of new concrete, and the production of the huge quantities of dismantled concrete waste form due to the deterioration of the reinforced concrete structure and obsolete structures create an ecological criticism. There is only a solution to this problem is to reuse this "concrete waste" like an aggregate in the new concrete production. Hence in the proposed study analysis the steel tubular columns filled with the recycled aggregate. Although this research topic are from about of 50 years, but the behavior of CFSTs columns under different types of loading conditions is not completely studied. Therefore, it is necessary to perform intensive parametric studies to know the behavior of CFST columns. This research paper addresses some of parameters those influence the behavior of the recycled aggregate concrete filled steel tubular column, which may effect by the relationship of the external diameter and the thickness of the steel tube, the compressive strength of the recycled aggregate concrete filling and the different loading rate.

1.1 Objectives

Conducting an experimental test program to study the behavior of steel tubes filled with recycled aggregate concrete taking into account the different factors such as:

1. The compressive strength of recycled aggregate concrete.
2. The ratio of the outer diameter to thickness of steel tube.
3. The loading rate applied to the steel tubes filled by RAC.

1.2 Shapes of CFST elements

There are different shapes for concrete-filled steel pipes as per the shape of confined steel tubes, like elliptical, circular, rectangular, square, L-shaped etc. Generally the circular and square sections are used for the CFST construction. The load bearing capacity of the CFST member is significantly influenced by the shape of its cross-section, and by the ratios of external diameter and thickness of the steel tube. In this experimental study only circular tubular steel sections are used to analysis the CFSTs columns.

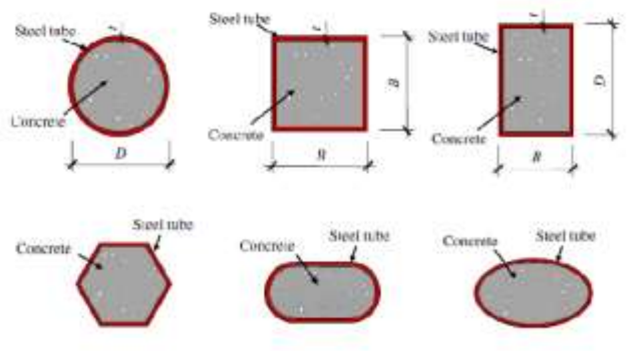

Fig -1: Different shapes of CFSTs Elements

2. MATERIALS AND EXPERIMENTAL DETAILS

2.1 Materials

In this study the Hollow circular steel tubes and concrete filled steel tubes are tested to found the behavior of concrete filled steel tubes columns.

2.1.1 Hollow Steel Tubes

The Hollow steel tubes samples were prepared from a long steel pipe (tube) using the cutting machine. Table-1 shows the Geometric properties of the empty steel tube specimens.

Table 1: The sample of properties of empty steel tubes

Sr. No.	Sample ID	D x t x L (mm)	D/t	Loading Speed (KN/s)
1	ST-1.1 R_{53}	167 x 3.1 x 350	54	53
2	ST-1.2 $R_{5.3}$	167 x 3.1 x 350	54	5.3
3	ST-2.1 R_{53}	114 x 3.6 x 250	32	53
4	ST-2.2 $R_{5.3}$	114 x 3.6 x 250	32	5.3
5	ST-3.1 R_{53}	114 x 5.6 x 250	20	53
6	ST-3.2 $R_{5.3}$	114 x 5.6 x 250	20	5.3

2.1.2 Concrete Filled Steel Tubes

In this study, eighteen samples of steel tubes filled with concrete of different sizes were tested. Table -1 shows the hollow steel tubes samples, which were used to make the CFST specimens. The interior surface of the empty tubes have been slightly roughened to increase the bonding strength between the concrete and the steel tubes. After that, the hollow tubes were filled with recycled aggregate concrete. Nine specimens were filled with M30 grade of concrete and the other nine were filled with M40 grade of concrete. Table 2 shows the CFST samples' properties.

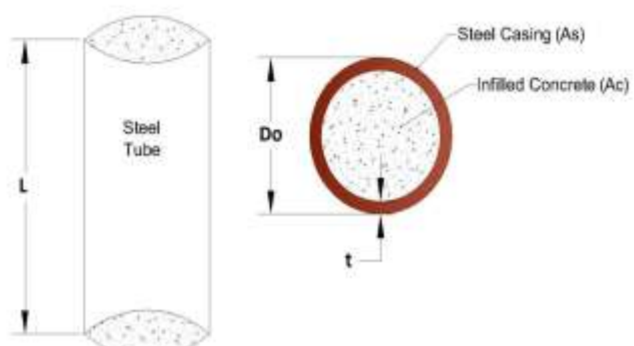

Fig -2: Specimen of CFST

The interior surfaces of the hollow steel tubes have been wetted to avoid the loss of the water content of the concrete mixture. As shown in Figure 2. The concrete was filled in three or four layers depending upon the size of the sample. Subsequently, the concrete layers were manually compacted 25 times at each layer with the temping rod.

Table 2: The Properties of CFSTs specimens

Sample ID	D x t x L (mm)	A_{steel} (mm²)	A_c (mm²)	Grade of Concrete (MPa)	D/t	Loading Rate (KN/s)
$ST_{1.1}M_{30}R_{53}$	167 x 3.1 x 350	806	20308	M30	54	53
$ST_{1.2}$ M_{30} R_{53}	167 x 3.1 x 350	806	20308	M30	54	53
$ST_{1.3}$ M_{30} R_{53}	167 x 3.1 x 350	806	20308	M30	54	53
$ST_{2.1}$ $M_{30}R_{53}$	114 x 3.6 x 250	635	8958	M30	32	53
$ST_{2.2}$ M_{30} R_{53}	114 x 3.6 x 250	635	8958	M30	32	53
$ST_{2.3}$ M_{30} R_{53}	114 x 3.6 x 250	635	8958	M30	32	53
$ST_{3.1}$ $M_{30}R_{53}$	114 x 5.6 x 250	978	8300	M30	20	53
$ST_{3.2}$ M_{30} R_{53}	114 x 5.6 x 250	978	8300	M30	20	53
$ST_{3.3}$ M_{30} R_{53}	114 x 5.6 x 250	978	8300	M30	20	53
$ST_{1.1}M_{40}$ $R_{5.3}$	167 x 3.1 x 350	806	20308	M40	54	5.3
$ST_{1.2}$ M_{40} $R_{5.3}$	167 x 3.1 x 350	806	20308	M40	54	5.3
$ST_{1.3}$ M_{40} $R_{5.3}$	167 x 3.1 x 350	806	20308	M40	54	5.3
$ST_{2.1}$ $M_{40}R_{5.3}$	114 x 3.6 x 250	635	8958	M40	32	5.3
$ST_{2.2}$ M_{40} $R_{5.3}$	114 x 3.6 x 250	635	8958	M40	32	5.3

$ST_{2.3}$ M_{40} $R_{5.3}$	114 x 3.6 x 250	635	8958	M40	32	5.3
$ST_{3.1}$ M_{40} $R_{5.3}$	114 x 5.6 x 250	978	8300	M40	20	5.3
$ST_{3.2}$ M_{40} $R_{5.3}$	114 x 5.6 x 250	978	8300	M40	20	5.3
$ST_{3.3}$ M_{40} $R_{5.3}$	114 x 5.6 x 250	978	8300	M40	20	5.3

The proportions of the filling concrete mixtures used to fill the CFSTs samples are presented in Table 3.

Table 3: Concrete Mix Proportions

Concrete type	W/C Ratio	Mix proportions (Kg/m³)				
		Cement	Coarse Aggregates	Fine Aggregates	Water	Plasticizer
M30	0.59	342	1173	720	205	-
M40	0.5	410	1187	638	205	1.1%

2.2 Experimental details

During this Study, samples of concrete cubes and cylinders, hollow circular steel tubes, concrete filled steel tubes (CFST) were tested. Figure 3 shows a systematic flow chart of this study's. Where the testing samples are arranged on basis of the parameters such as loading rate (R), compressive strength of infilled concrete and the ratio of Diameter-to-thickness of steel tube.

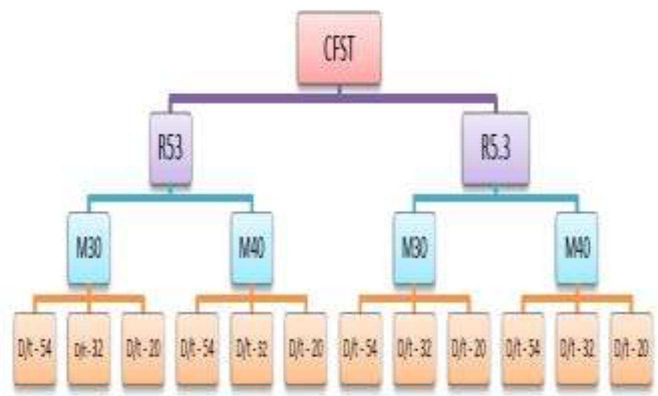

Fig.- 3: Testing Program Matrix

3. RESULTS AND DISCUSSION

3.1 Material Testing

3.1.1 Empty Steel Tubes Test

To study the behavior of the CFST elements, 10 samples of circular cross-section of steel tube with different grade of concretes and thickness of steel tube under the almost static axial compression loading were tested. Table 4 shows the summary of the tests, where R_{53} and $R_{5.3}$ defines the loading rate of 53 KN/s and 5.3 KN/s, respectively, and also, $\mathbf{t_{3.1}}$, $\mathbf{t_{5.6}}$ **and** $\mathbf{t_{3.6}}$ refers to the thickness of steel tubes of 3.1mm, 5.6mm, and 3.6mm, respectively.

Table 4: Compressive strength of Empty Steel Tubes

ID	Ultimate Load (KN)	Ultimate Stress (MPa)	AVR. Ultimate Load (KN)	AVR. Ultimate Stress (MPa)
ST -1.1 $t_{3.1}$ R_{53}	563	677		-
ST -3.1 $t_{5.6}$ R_{53}	789	807	789	807
ST -3.2 $t_{5.6}$ R_{53}	789	807		
ST -2.1 $t_{3.6}$ R_{53}	480	757	481	758
ST -2.2 $t_{3.6}$ R_{53}	482	759		
ST -1.1 $t_{3.1}$ $R_{5.3}$	556	668	-	-
ST -3.1 $t_{5.6}$ $R_{5.3}$	766	784	767	784
ST -3.2 $t_{5.6}$ $R_{5.3}$	767	784		
ST -2.1 $t_{3.6}$ $R_{5.3}$	464	731	467	736
ST -2.2 $t_{3.6}$ $R_{5.3}$	471	742		

For both loading rates, the leading mode of failure was local buckling. It was noted that the smaller ratio was sufficienrt to prevent Euler buckling, but local buckling in the case of all specimens was located near the loading end.

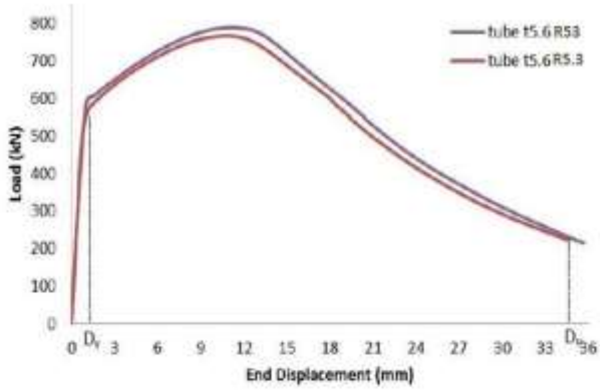

Fig.-5: The relation b/w load to End displacement of the empty steel tube under different loading rates

Figure 5 shows the relationship between the stress displacement of hollow steel tubes with a thickness of 5.6 mm and the external diameter of 114 mm. The graph shows the effect of different load speeds, Apparently, the rigidity of the empty steel tubes is not affected by the change in loading rates. But, the performance and final stresses are slightly increased with the increase in loading speed due to the effects of high loading speeds on the behavior of the material. Furthermore, the ductility of the section is not affected by the loading rate.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 07 | July 2019 www.irjet.net p-ISSN: 2395-0072

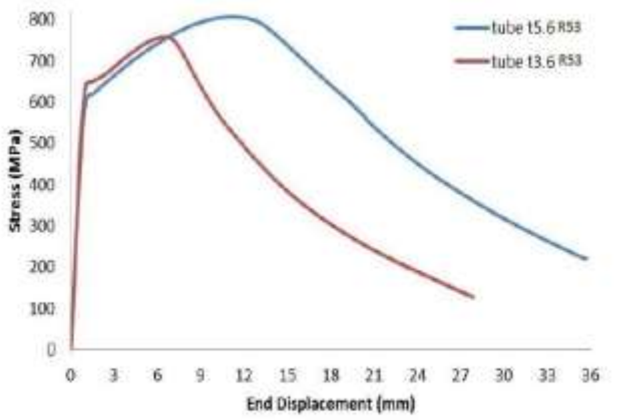

Fig. - 6: The relation b/w Stress-End Displacement of Empty Steel Tube with Different Thicknesses of tube

Figure 6 shows the stress-displacement curves of hollow steel tubes of different thicknesses of 5.6mm and 3.6mm, denoted by $t_{5.6}$ and $t_{3.6}$, with external diameter of 114mm. Fig-6 shows the effect of different steel tube thicknesses under given loading rate and fixed for both samples which is 53 KN/s. Note that, the stiffness of the empty steel tubes is hardly affected with the change in the thickness of steel tube . However, the ultimate stress, the toughness and the ductility have increased with the increase in the tube thickness.

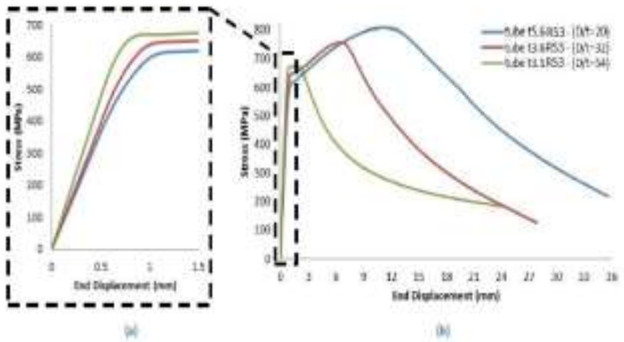

Fig. - 7: Stress-End Displacement relationship of Empty Steel Tube with Different D/t Ratios

Figure 7 shows the stress-displacement diagrams of three empty steel tubes with different External diameters and tube thicknesses under the loading rate of 53 KN/s

3.2 CFST Test Results

The test results of thirty three CFST specimens are summarize in Table 5, where R60 and R0.6 refers to the applied loading rate of 53 KN/s and 5.3 KN/s, M30 and M40 refers to a concrete infill compressive strength of 30MPa and 40MPa, and D167t3.1, D114t3.6 and D114t5.6 refers to the D/t ratio of 54, 32 and 20, respectively. The CFST ultimate stress (MPa) in Table 5 is calculated by dividing the ultimate load carrying capacity (KN) by the total area of the CFST element.

Table 5: Test Results of Concrete Filled Steel Tubes

ID	Ultimate Load (KN)	Ultimate Stress (MPa)	AVR. Ultimate Load (KN)	AVR. Ultimate Stress (MPa)
R53M40 D167 t3.1 -ST 1.1	1946	889	1952	**89**
R53M40 D167 t3.1 -ST1.2	1954	89		
R53M40 D167 t3.1 –ST 1.3	1955	89		
R53M40D114 t5.6 -ST 3.1	1369	134	1395	**137**
R53M40 D114 t5.6 -ST3.2	1407	138		
R53M40 D114 t5.6 –ST 3.3	1408	138		
R53M30D114 t5.6 -ST3.1	1334	131	1309	**128**
R53M30D114 t5.6 –ST3.2	1315	129		
R53M30D114 t5.6 -ST3.3	1278	125		
R53M30D167 t3.1 –ST1.1	1735	79	1720	**79**
R53M30D167 t3.1 –ST1.2	1705	78		
R53M40D114 t3.6 –ST2.1	1110	109	1109	**109**
R53M40 D114 t3.6 –ST2.2	1120	110		
R53M40 D114 t3.6 –ST 2.3	1097	108		
R53F30D114 t3.6 –ST2.1	1074	105	1038	**102**
R53M30D114 t3.6 -ST2.2	1010	99		
R53M30D114 t3.6 –ST 2.3	1029	101		
R5.3M40 D167 t3.1 -ST 1.1	1869	85	1873	**86**
R5.3M40 D167 t3.1 -ST1.2	1876	86		
R5.3M40D114 t5.6 -ST 3.1	1359	133	1365	**134**
R5.3M40 D114 t5.6 -ST3.2	1360	133		
R5.3M40 D114 t5.6 –ST3.3	1376	135		
R5.3M30D114 t5.6 -ST3.1	1332	131	1314	**129**
R5.3M30D114 t5.6 -ST3.2	1301	128		
R5.3M30D114 t5.6 -ST3.3	1309	128		
R5.3M30D167 t3.1 -ST1.1	1758	80	1710	**78**
R5.3M30D167 t3.1 -ST1.2	1661	76		

R5.3M40D114 t3.6 -ST2.1	1097	107	1095	**107**
R5.3M40 D114 t3.6 -ST2.2	1087	107		
R5.3M40 D114 t3.6 -ST 2.3	1100	108		
R5.3M30D114 t3.6 -ST2.1	1055	103	1042	**102**
R5.3M30D114 t3.6 -ST2.2	1045	102		
R5.3M30D114 t3.6 -ST 2.3	1028	101		

For a given loading rate and condition and sectional properties of CFSTs, a set of two or three specimens are tested. Afterwards, the average test results of each set is used for further analysis. An example of these sets is provided in Figure 8 with a relationship of Stress and End displacement.

Figure 8 shows the relationship of load-deformation of three CFST samples with identical properties and similar testing conditions. The average ultimate axial capacity of the three samples is 1952 KN, such that the percentage difference of any of the samples and the average does not exceed 0.4%. In addition, the post ultimate load decreases with a decreasing rate resulting in reduction of the section's ability to dissipate energy. On the other hand, the stiffness of the R53M40D167t3.1-ST 1.1 and R53M40D167t3.1–ST1.3 is almost the same while R53M40D167t3.1-ST 1.2 is a little bit different.

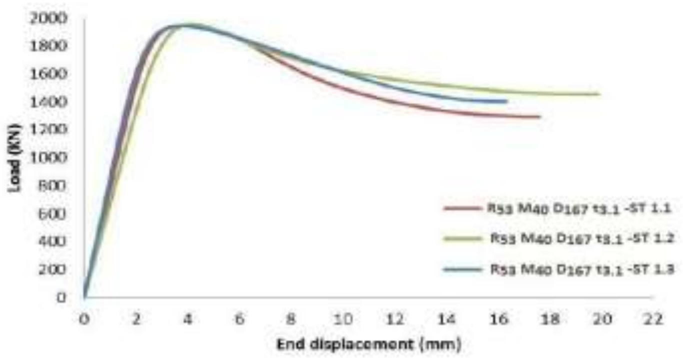

Fig - 8: Load-End displacement diagram of three CFST elements with D/t ratio of 54, M40 and loading rate of 53KN/s

Figure 9 shows the maximum compressive strength of a CFST element with its relation. The CFST elements are divided into four different groups based on the loading speed and the grade of the filled concrete. It is noted that the speed of reduction of the final tension is influenced by the compressive strength of the concrete filling and by the loading speed that can be observed by comparing the results of the CFST elements with $\mathbf{M_{40}R_{53}}$ and those with $\mathbf{M_{30}R_{5.3}}$.

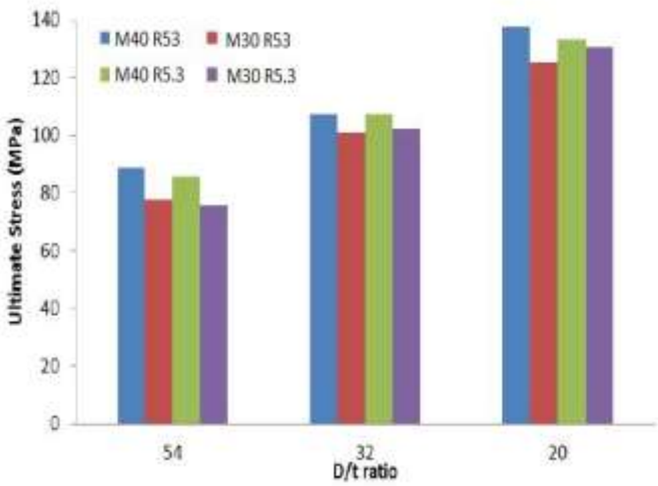

Fig. - 9: D/t Ratio vs. ultimate stress chart of CFST element

3.3 Comparison of test results with different formulas available

Results for the load carrying capacity of the CFST specimens (P_{exp}) are obtained from the corresponding test results. These load bearing capacity of CFST are summarized in Table 5.

The experimental maximum values of compressive loads were compared with the theoretical values (P_{the}), which were calculated from the ultimate axial capacities of individual both the steel tube and infilled concrete by the following equation:

$$P_{the} = Ac\, fck + As\, fy$$

Where

Ac = the cross-sectional area of the infilled concrete,
As = the cross-sectional area of the steel tube,
fck = the grade of infilled concrete and
fy = the Grade of the steel tube.

Mander et al. proposed a model for confined concrete conducting on circular shaped transverse reinforcements. In this model, the compressive strength of confined concrete may calculate by the following equation.

$$f_{cc} = f_{co}\left(-1.254 + 2.254\sqrt{1 + \frac{7.94 f_1}{f_{co}}} - 2\frac{f_1}{f_{co}}\right)$$

Where

fcc = the compressive strength of confined concrete,
fco = the strength of unconfined concrete and
f_1 = the effective lateral confining stress on the concrete.

The confining stress f1 may determined by the equilibrium of forces as:

$$f1 = \frac{2\sigma\theta t}{D}$$

Where

D and **t** are the External diameter and thickness of tube respectively,

The value of σ_θ is assumed to be 0.1 fy.

The load bearing capacity of CFT may determined by

$P_{man} = Ac\, fcc + As\, fy.$

The load carrying capacity of presented model by the Mander were calculated and were compared with those of the experimental results and a ratio of the experimental to Mander's values was determined.

Georgios Giakoumelis [12] had also present a modified coefficient for the equation, given by ACI for determining the compressive strength of a CFST column by taking into consideration the concrete confinement. The modified equation is given as:

$P_{ACI} = 1.3Ac\, fc + As\, fy.$

The values obtained from the above equation are comparable to those results which obtained from the experiment, especially for D/t ratios between 25 and 60.

Table 6 Comparison of load bearing capacity of CFSTs filled with of concrete grade M30 and M40 with results obtained by the available equation

Infilled Concrete Grade	D/t	$P_{THE.}$ (KN)	P_{ACI} (KN)	P_{MAN} (KN)	$P_{EXP.}$ (KN)	Pexp/Pthe.	Pexp/Paci	Pexp/Pman.
M40	20	1166	1091	1340	1365	1.2	1.25	1.018
	32	975	894	1101	1095	1.12	1.22	0.99
	54	1777	1594	1951	1872	1.05	1.17	0.959
M30	20	1033	978	1200	1314	1.27	1.34	1.095
	32	831	978	954	1042	1.25	1.065	1.09
	54	1452	1318	1623	1709	1.17	1.29	1.05

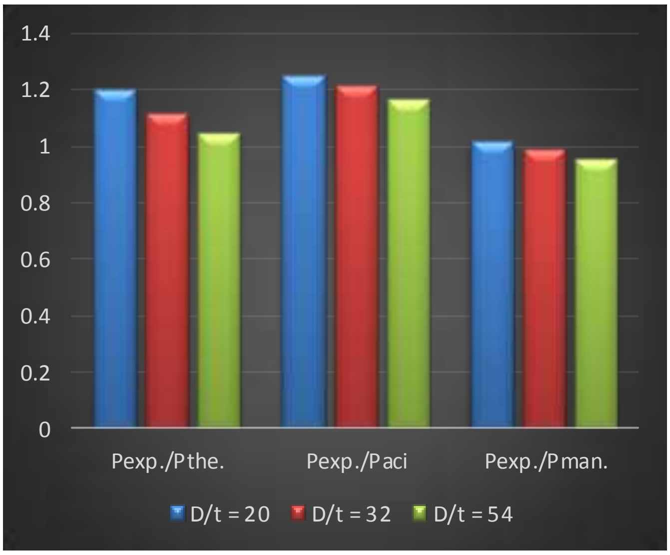

Fig.-10: Comparison of load carrying capacity of CFSTs infilled by M40 grade of concrete with the calculated values

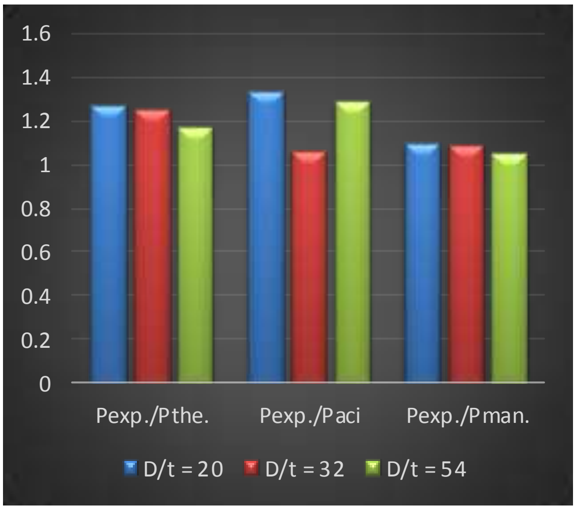

Fig.-11: Comparison of load carrying capacity of CFSTs infilled by M30 grade of concrete with the calculated values

4. SUMMARY AND CONCLUSIONS

In this research, the compression behavior of steel tubes filled with recycled aggregate concrete (CFST) under axial compression loads is studied experimentally.

For CFST columns, the effects of three main parameters; in this study, the compressive strength of the concrete, the diameter-to-thickness ratio and the load rate are considered. It is also noted that the ductility of the column decreases with increasing strength of the concrete filling for higher ratios, but for lower ratios, the opposite is true. The increase in the ratio not only reduces the stiffness of the CFST element but also its axial force due to the decrease in confinement. The increase in applied loading speed does not seem to affect the rigidity of the section, although it slightly increases its axial resistance. In reality, no significant change in the behavior of the section is observed under the two different loading speeds. This could be attributed to the relatively low percentages required by the limits of the test machine.

Several equations and formulas are designed to estimate the axial capacity of CFST columns. In this study a comparison is made between the analytical values using some suggested equations and the experimental results presented.

REFERENCES

[1] Tsuji, B., Nakashima, M. and Morita, S., "Axial Compression Behavior of Concrete Filled Circular Steel Tubes," in Third International Conference on Steel-Concrete Composite Structures, Fukuoka, Japan, 1991.

[2] S. T. Zhong, "The Concrete Filled Steel Tubular (CFST) Structures in China," in the Third International Conference on Steel-Concrete Composite Structures, Fukuoka, Japan, 1991.

[3] T. Nishino and Furukawa, T., "strength and deformation capacities of circular hollow section steel member reinforced with carbon fiber," in Seventh Pacific Structural Steel conference, Long Beach, CA, 2004.

[4] P. K. Neogi, H. K. Sen and J. C. Chapman, "Concrete-filled tubular steel columns under eccentric loading," The Structural Engineer, vol. 47, no. 5, p. 187–95, 1969.

[5] M. D. O'Shea and R. Q. Bridge, "Design of circular thin-walled concrete filled steel tubes," Journal of Structural Engineering, vol. 126, no. 11, pp. 1295-1303, November 2000.

[6] S. P. Schneider, "Axially loaded concrete-filled steel tubes," Journal of Structural Engineering, vol. 124, no. 10, p. 1125–1138, 1998.

[7] J. H. Shan, R. Chen, W. X. Zhang, Y. Xiao, W. J. Yi and F. Y. Lu, "Behavior of Concrete Filled Tubes and Confined Concrete Filled Tubes under High Speed Impact," Advances in Structural Engineering, vol. 10, no. 2, pp. 209-218, 2007.

[8] Yu, Z., Ding, F. and Cai, C. S., "Experimental behavior of circular concrete-filled steel tube stub columns," Journal of Constructional Steel Research, no. 63, p. 165–174, 2006.

[9] Sakino, K., Nakahara, H., Morino, S. and Nishiyama, I., "Behavior of Centrally Loaded Concrete-Filled Steel-Tube Short Columns," JOURNAL OF STRUCTURAL ENGINEERING, vol. 2, no. 130, pp. 180-188, FEBRUARY 2004.

[10] Gupta, P. K., Sarda, S. M. and Kumar, M. S., "Experimental and computational study of concretefilled steel tubular columns under axial loads," Journal of Constructional Steel Research, no. 63, p. 182–193, 2007.

[11] Ellobody, E., Young, B. and Lam, D., "Behaviour of normal and high strength concrete-filled compact steel tube circular stub columns," Journal of Constructional Steel Research, no. 62, p. 706–715, 2006.

[12] Giakoumelis, G. and Lam, D., "Axial capacity of circular concrete-filled tube columns," Journal of Constructional Steel Research, vol. 7, no. 60, p. 1049–1068, 2004.

[13] Zhong, S. and Zhang, S. M., "Application and development of concrete-filled steel tubes (CFST) in high-rise buildings," Advances in Structural Engineering, vol. 2, no. 2, p. 149–159, 1999.