



# EXPERIMENTAL BEHAVIOUR OF STEEL TUBULAR COLUMNS FOR VARYING IN FILLED CONCRETE

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This paper investigates the behaviour of axially-loaded tubular columns filled with M20 grade concrete and partially replaced concrete. The parameters varying in the study are slenderness ratio (13.27, 16.58 & 19.9), and normal M20 grade concrete, partially replaced quarry dust and concrete debris. The effects of the various concrete mixes and composite action between the steel tube and the concrete core are studied and a graph visualizing the differences between the load carrying capacity and the axial deflection is plotted. Some of the performance indices like the Ductility Index (DI), Concrete Contribution Ratio (CCR), Confinement Index ( $\theta$ ) and Strength Index (SI) are also evaluated and compared amongst the CFST columns. From the results it has been noted that an increase in the L/D ratio decrease the behaviour of the composite columns irrespective of the in filled materials. The composite action was achieved in the CFST columns filled with partially replaced quarry dust and concrete debris when compared with hollow steel columns. The load carrying capacity of the CFST column increases by 32 % compared with the hollow tubular columns.

*Keywords:* composite column, recycled aggregate, slenderness ratio, strength index, confinement index, CFST

## 1. INTRODUCTION

Concrete-filled steel tubular (CFST) columns have been used in different and varied applications, such as bridge piers which are continuously subjected to impact from traffic, columns that support storage tanks, railway decks, piles and columns in high-rise buildings. Because of the increased use of these types of composite columns, interest in the behaviour of these types of columns triggered

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many theoretical and experimental studies. Although CFST columns are suitable for tall buildings in seismic regions, their use has been limited due to a lack of information about the true strength and the in-elastic behaviour of CFST composite action. The main advantage of concrete in CFST is that it delays the local buckling of the tube wall and concrete itself, in its restrained state and also able to sustain higher stresses and strains when it is unrestrained. The concrete is subjected to a tri-axial condition which results in increased strength. Research on CFT columns has been ongoing worldwide for many decades, with significant contributions saving has been made on tensile strength and ductility, while concrete members have the advantages of high compressive strength and fire resistance. Bo Wu et.al [1] have studied the several new proposed kinds of structural members containing demolished concrete with a distinctly larger size than conventional recycled aggregates. Bonet J.L. and Montalvá J.M [2] conducted experiments on thirty six rectangular and square tubular columns filled with normal and high strength concrete and subjected them to a non-constant bending moment distribution with respect to the weak axis. Chithira K. and Baskar K [3], have carried out an experimental and numerical study on the behaviour of concrete filled circular steel tubular columns under eccentric load condition with and without shear connectors. Dong et.al [4] have investigated the structural behaviour of normal and recycled aggregate concrete filled steel tube (RACFT) columns externally strengthened with carbon fibre reinforced polymer (CFRP) sheets and subjected to axial loading. Ganesh Prabhu and Sundararaja [5] focused on experimentally and analytically investigating the suitability of carbon fibre reinforced polymer (CFRP) strip composites in strengthening CFST members under compression. Georgios Giakoumelis and Dennis Lam [6] studied the behaviour of circular concrete-filled steel tubes (CFT) with various concrete strengths under axial compression. Haedir and Jimmy [7] presented the external bonding of carbon fibre reinforced polymer (CFRP) sheets with epoxy resin effectively used to strengthen and repair concrete structures. Viveka and Shanmugavalli [8] assessed the feasibility of strengthening circular hollow steel tubular sections subjected to compression to develop or predict the suitable wrapping of FRP to enhance its structural behaviour.

## 2. MATERIALS AND METHODS

A total of twelve concrete filled tubular columns were tested under axial compression. The parameters varying in the study were the slenderness ratio ( $L/D$ ) and in filled concrete. The dimensions of the specimens are shown in Table 1. The tubular pipes were made for three different lengths of 800 mm, 1000 mm, & 1200 mm. The tubular columns have yield strength and ultimate

strength of  $360 \text{ N/mm}^2$  and  $550 \text{ N/mm}^2$ , respectively, with a Poisson ratio of 0.3. The tubular columns were filled with normal M20 grade concrete and partially replaced concrete. The coarse and fine aggregates of the M20 grade concrete were replaced by 30 % concrete debris and 30 % quarry dust. The compressive strengths of the normal concrete (NC), concrete with partially replaced concrete debris (CD), and concrete with partially replaced quarry dust (QD) were obtained as  $22.32 \text{ N/mm}^2$ ,  $20.56 \text{ N/mm}^2$ , and  $18.96 \text{ N/mm}^2$  respectively. The specimens, test progress, and failed specimens are shown in Figs. 1 through 3

Table 1. Dimensions of the specimens

Sl. No	Description	Specimen ID	L (mm)	D (mm)	t (mm)	(L / D )
1	Column without In filled Concrete	HS	800	60.3	3.2	13.27
2	Column with Normal M20 Concrete	NC	800	60.3	3.2	13.27
3	Column with partially replaced debris concrete	CD	800	60.3	3.2	13.27
4	Column with partially replaced Quarry dust	QD	800	60.3	3.2	13.27
5	Column without In filled Concrete	HS	1000	60.3	3.2	16.58
6	Column with Normal M20 Concrete	NC	1000	60.3	3.2	16.58
7	Column with partially replaced debris concrete	CD	1000	60.3	3.2	16.58
8	Column with partially replaced Quarry dust	QD	1000	60.3	3.2	16.58
9	Column without In filled Concrete	HS	1200	60.3	3.2	19.90
10	Column with Normal M20 Concrete	NC	1200	60.3	3.2	19.90
11	Column with partially replaced debris concrete	CD	1200	60.3	3.2	19.90
12	Column with partially replaced Quarry dust	QD	1200	60.3	3.2	19.90



Fig. 1. Concrete filled steel tubular specimens

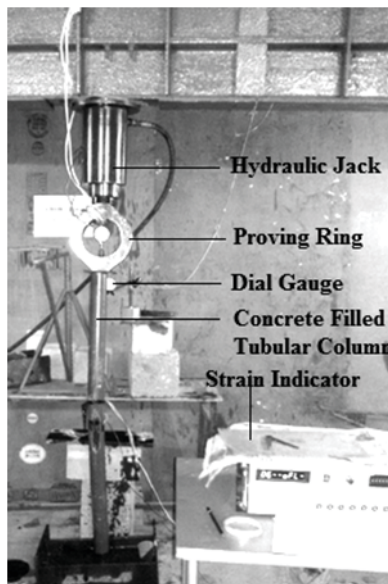


Fig. 2. Test in progress of CFST column specimen



Fig. 3. Tested concrete filled tubular columns

### 3. RESULT AND DISCUSSION

#### 3.1. EFFECTS OF PARTIALLY REPLACED CONCRETE

The behaviours of concrete filled tubular columns with partially replaced concrete (by quarry dust and concrete debris) in the standard M20 grade concrete were studied. The load- deflection behaviours of the composite column for the different slenderness ratios are shown in Figs. 4 through 6. The percentage increase in the deflection of the composite columns and the non - composite column (hollow column) is 25 to 32 % for three different slenderness ratios of 13.27, 16.58, and 19.90. For the slenderness ratio of 13.27, the percentage decrease in the deflection of the column with concrete debris (CD) and quarry dust (QD) is 14.3 % and 19 %, when compared with normal M20 grade concrete filled column. The percentage decreases in the deflection for the slenderness ratio of 16.58 is 13.6 % and 25 % for change in concrete in the column from normal concrete to quarry dust. The percentage decrease in the deflection of the column with CD and QD is 4 % and 12 % compared with the normal concrete column for the slenderness ratio of 19.90. The load carrying capacity of the composite columns for different slenderness ratio was compared in the bar chart diagram and it is shown in Fig. 7.

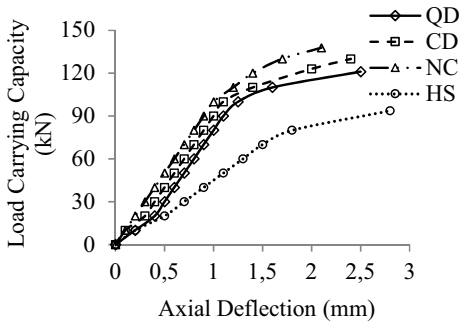


Fig. 4. Load-Deflection behaviour of CFST columns ( $L/D = 13.27$ )

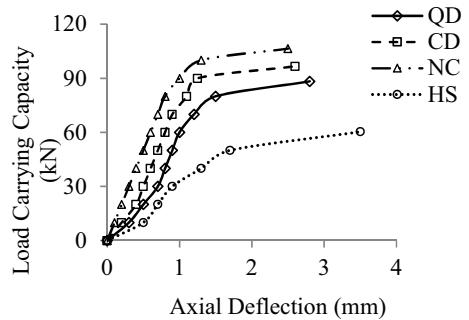


Fig. 6. Load-Deflection behaviour of CFST columns ( $L/D = 19.90$ )

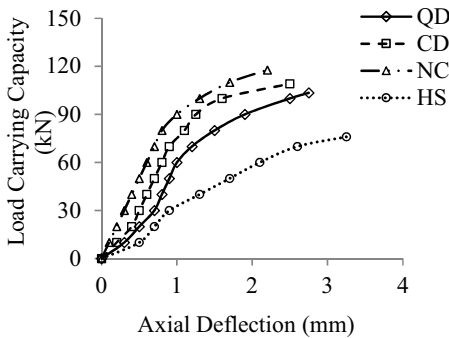


Fig. 5. Load-Deflection behaviour of CFST columns ( $L/D = 16.58$ )

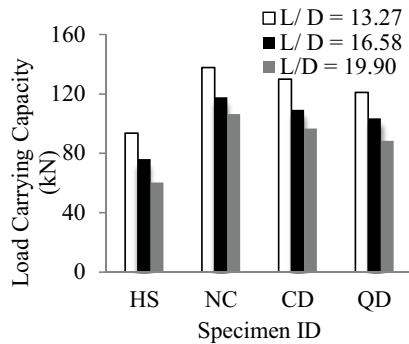


Fig. 7. Load carrying capacity of CFST columns

### 3.2. CONCRETE CONFINEMENT RATIO AND STRENGTH INDEX

To compare the ductility, strength enhancement and role of the concrete component in the CFST columns, some important parameters are defined and evaluated for the differently filled concrete samples (i.e normal concrete, concrete debris, and quarry dust); the Ductility Index (DI), Strength Index (SI), and Concrete Contribution Factor (CCR) respectively.

The concrete contribution ratio (CCR) is defined as the ratio between the maximum load of the composite column and the empty hollow steel column.

$$CCR = \frac{N_{\max(\text{exp})}}{N_{\max(\text{hollow})}}$$

As there are too many variables that affect this index, three combined variables which influence the main parameters affecting the test were selected: section behaviour (confinement index,  $\theta$ ), relative slenderness ( $\lambda$ ), and the strength of concrete ' $f_{ck}$ '. The confinement index is defined as:

$$\theta = \frac{A_s f_y}{A_c f_{ck}}$$

Figs. 8 and 9 show the compression between the CCR and the confinement index of the CFST columns. It was found that an increase in the L/D ratio, increases the concrete confinement ratio, irrespective of the infilled concrete.

The strength index (SI) is defined as the ratio between the axial load carrying capacity of the CFST section to the sum of the strengths of the steel tube and the concrete combined.

$$SI = \frac{N_{\max}}{N_{pl} R_d} = \frac{N_{\max}}{A_c f_{ck} + A_s f_y}$$

The increase in the L/D ratio, decreases the strength index of the CFST columns. Fig. 10 gives the variation of the strength index for concrete filled steel tubular specimens.

The ductility index (DI) is defined as the ratio between the deflection at the point in which the load carrying capacity dropped to 85 % to the deflection at the maximum load.

$$DI = \frac{\delta(85\% \text{ of max})}{\delta(\text{max})}$$

The increase in the DI is 10 % for the columns filled with concrete debris than the column with normal concrete. The percentage increase in the DI for the column with quarry dust is 9 % compared with normal concrete filled columns. The variations of the ductility index for the CFST columns are shown in Fig. 11. Table 2 gives the consolidated test results and calculated performance indices.

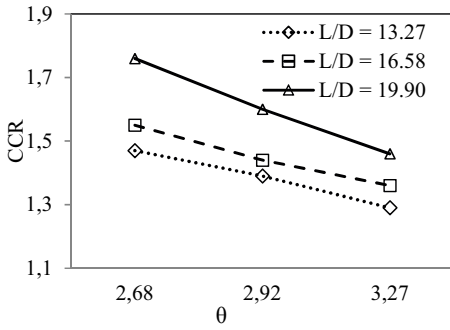


Fig. 8. Concrete contribution ratio versus confinement index

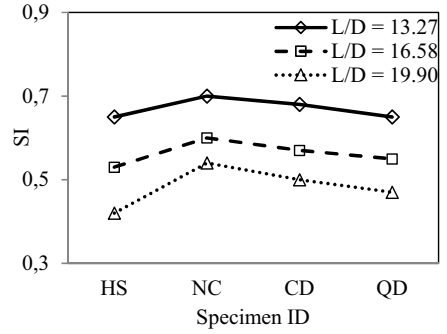


Fig. 10. Strength index of CFST columns

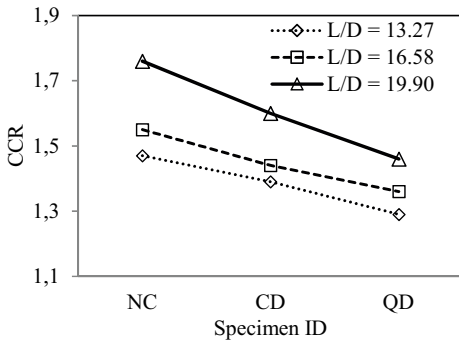


Fig. 9. Concrete contribution ratio of CFST columns

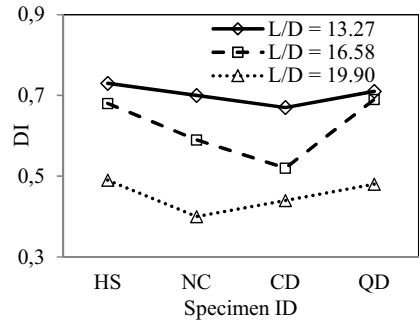


Fig. 11. Ductility index of CFST columns



Table 2. Results of the CFST columns

Sl. No	Specimen ID	L mm	D mm	t mm	$f_{ck}$ N/mm <sup>2</sup>	L/D	$N_{max( exp)}$ kN	DI	CCR	$\theta$	SI
1	HS	800	60.3	3.2	0	13.27	93.69	0.64	-	-	0.65
2	NC	800	60.3	3.2	23.50	13.27	137.83	0.67	1.47	2.68	0.70
3	CD	800	60.3	3.2	21.56	13.27	129.98	0.58	1.39	2.92	0.68
4	QD	800	60.3	3.2	19.23	13.27	121.06	0.50	1.29	3.27	0.65
5	HS	1000	60.3	3.2	0	16.58	76.03	0.74	-	-	0.53
6	NC	1000	60.3	3.2	23.50	16.58	117.72	0.59	1.55	2.68	0.60
7	CD	1000	60.3	3.2	21.56	16.58	109.19	0.52	1.44	2.92	0.57
8	QD	1000	60.3	3.2	19.23	16.58	103.50	0.69	1.36	3.27	0.55
9	HS	1200	60.3	3.2	0	19.90	60.33	0.49	-	-	0.42
10	NC	1200	60.3	3.2	23.50	19.90	106.44	0.40	1.76	2.68	0.54
11	CD	1200	60.3	3.2	21.56	19.90	96.63	0.44	1.60	2.92	0.50
12	QD	1200	60.3	3.2	19.23	19.90	88.29	0.48	1.46	3.27	0.47

#### 4. CONCLUSIONS

The results obtained from the tests on the composite columns presented in this paper allow the following conclusions to be drawn.

1. The use of concrete debris and quarry dust has resulted in improvement in the structural behaviour of the composite columns subjected to axial loading when compared with hollow steel columns.
2. Usage of recycled aggregate concrete in steel tubular columns is not only a waste utilisation technique, but also reduces costs of the in filled concrete.
3. The enhancement of strength in the case of the CFST columns depends on the compressive strength of the filled concrete and on the confinement effect.
4. The load carrying capacity of the CFST column increases by 32 % comparing with hollow tubular columns irrespective of the in filled concrete.

## SYMBOLS

CFST	-	Concrete Filled Steel Tubular
HS	-	Hollow Column
NC	-	Normal Concrete
CD	-	Concrete Debris
QD	-	Quarry Dust
D	-	Outer diameter of the column
t	-	Thickness of the steel tube
$f_{ck}$	-	Characteristic compressive strength of the concrete cube

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## BADANIE DOŚWIADCZALNE STALOWYCH SŁUPÓW RUROWYCH O RÓŻNYM WYPEŁNIENIU BETONEM

*Słowa kluczowe:* słup zespolony, kruszywo pochodzące z recyklingu, wskaźnik smukłości, wskaźnik wytrzymałości, wskaźnik zamknięcia, CFST

### PODSUMOWANIE:

Stalowe słupy rurowe wypełnione betonem (CFST) są wykorzystywane do różnorodnych zastosowań, takich jak filary mostów, które są stale narażone na oddziaływanie ruchu ulicznego, słupy obsługujące zbiorniki magazynowe, pokłady kolejowe, pale oraz słupy stosowane w wysokich budynkach. Ze względu na zwiększone wykorzystanie tego rodzaju słupów zespolonych, zainteresowanie zachowaniem tego typu słupów przyczyniło się do przeprowadzenia wielu badań teoretycznych i eksperymentalnych. Chociaż słupy CFST nadają się do wykorzystania w wysokich budynkach na obszarach sejsmicznych, ich zastosowanie zostało ograniczone z powodu braku informacji o prawdziwej wytrzymałości i nieelastycznym zachowaniu CFST. Główną zaletą betonu w CFST jest to, że opóźnia on lokalne wybočenje ściany rury i samego betonu, w umiarkowanym stanie, a zatem jest w stanie utrzymać większe obciążenia i naprężenia niż w stanie nieumiarkowanym.

W niniejszej pracy zbadano zachowanie słupów rurowych obciążonych osiowo, wypełnionych betonem klasy M20 i częściowo zastąpionym betonem. Badaniu poddano łącznie 12 próbek, w celu zbadania zachowania stalowych słupów rurowych wypełnionych betonem przy różnym wypełnieniu. Parametry zróżnicowane w badaniu są współczynnikiem smukłości (13,27, 16,58 i 19,9) i betonem standardowej klasy M20, częściowo zastąpionym pyłem z kamieniołomu i odławkami betonu. Badano wpływ różnych działań betonowych i kompozytowych w rurze stalowej i rdzeniu betonowym, a ponadto sporządzono wykres obciążenia i ugięcia osiowego. Niektóre wskaźniki wydajności, takie jak Wskaźnik Plastyczności (DI), Współczynnik Udziału Betonu (CCR), Wskaźnik Zamknięcia ( $\theta$ ) oraz Wskaźnik Wytrzymałości (SI) zostały również poddane ocenie i porównane z słupami CFST. Na podstawie wyników stwierdzono, że wzrost wskaźnika L/D ogranicza działanie słupów zespolonych, niezależnie od wypełnionych materiałów. Złożone działanie osiągnięto w słupach CFST wypełnionych częściowo wymienionym pyłem z kamieniołomu i odławkami betonu, w porównaniu z pustymi stalowymi słupami. Wykorzystanie odławków betonu i pyłu z kamieniołomu doprowadziło do poprawy zachowania konstrukcji słupów zespolonych poddanych obciążeniu osiowemu, w porównaniu do pustych stalowych słupów. Zwiększenie wytrzymałości w przypadku słupów CFST zależy od wytrzymałości na ściskanie wypełnionego betonu oraz od wskaźnika zamknięcia. Nośność słupa CFST wzrasta o 32% w porównaniu z pustymi słupami rurowymi, niezależnie od wypełnienia betonem. Wykorzystanie kruszywa pochodzącego z recyklingu w stalowych kolumnach rurowych jest nie tylko techniką utylizacji odpadów, lecz zmniejsza także koszt wypełnienia betonem.