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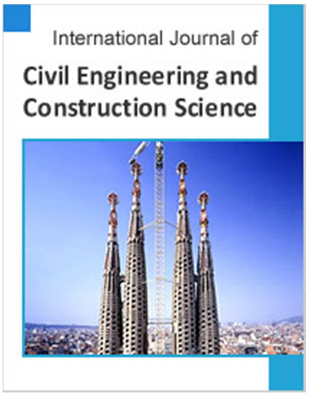

Parametric Study on the Lateral Load Carrying Capacity of CFST Columns

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Abstract
Use of Concrete filled steel tube (CFST) columns are increasing in civil engineering structures due to its abundant structural benefits like excellent seismic behaviour, ultimate load bearing capacity, fire resistivity, excellent ductility and energy absorption capacity, especially in zones of high seismic risk. Numerical study on seismic behaviour of CFST columns are presented in this paper. OpenSEES is used to model the CFST columns. Changing the different parameters like diameter-to-thickness ratio (D/t) ratio, steel grade, concrete grade, slenderness ratio and axial force ratio lateral load carrying capacity of CFST columns under cyclic load is investigated. Results shows that the lateral load capacity significantly increased by D/t ratio, increase in steel grade and decrease in slenderness ratio and noticeable increase due to increase of concrete grade and decrease in axial force ratio.

1. Introduction

Concrete filled steel tube (CFST) columns are widely used in civil engineering structures [1-3]. CFST columns are the composite structures in which steel tube is filled with concrete as shown in Figure 1. Uses of CFST in Civil Engineering Structures has been increasing due to its abundant structural benefits. The steel tube serves as a formwork for casting concrete which reduces the overall construction cost of the structure. The steel tube provides confinement to the to the core's strength and ductility while the concrete core delays bending and buckling of the steel tube. [2-8]. CFST have been used in frame structures as girder, column in bridges, transmission tower, offshore and power plant structures [10]. CFST columns are suitable for tall buildings, bridges with very tall piers in high seismic regions since concrete delays the local buckling of steel hollow sections and increases the ductility of the section significantly. The use of CFST columns has much advantages over hollow tube structures as it reduces the cost by increasing the floor area by a reduction in the required size of column [10-11]. This is very important in the design of tall buildings in cities where the cost of spaces is extremely high.

The confinement of concrete is influenced by the diameter-to-thickness ratio (D/t) of the tubes. Han et al. [10] has demonstrated that the ultimate strength for a CFST is even larger than the summation of the individual strength of the steel tube and the RC column, which is described as "1 (steel tube) + 1 (concrete core) greater than 2 (simple summation of the two materials)". Hence, use of CFST can be efficient for the bridge piers and other columns.

This paper presents the parametric study simulating the CFST columns with varying different parameters to clarify the effect of such increase on the load carrying capacity and on the post-yield behaviour of CFST columns. In this paper, the five different models are created by using different thickness of steel to study effect of increase in thickness of steel tube on behaviour of CFST column. The five different models are created by using different concrete cube strengths to study effect of grade of concrete on behaviour of CFST column, four different models are created by using different steel grade to study effect of grade of steel on behaviour of CFST column, five models for the effect of axial force ratio and the six different models are created by using different column to study effect of slenderness on behaviour of CFST column.

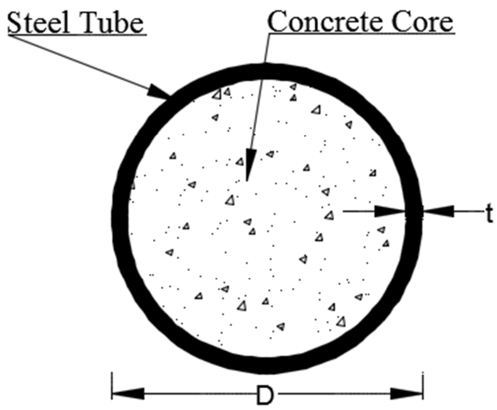


Figure 1. *Cross Section of Circular CSFT column.*

2. Modeling

In order to simulate the actual behaviour of CFST columns, the main components of these columns have to be modelled properly. A simplified nonlinear fibre element method was developed in this paper for circular CFT columns under the constant axial load and cyclically increasing lateral loading. The fibre element is modelled by using the open system for earthquake engineering simulation (OpenSEES) is contrived to efficiently predict the seismic behaviour of the CFST column. The details of fibre and cantilever column model is shown in figure 3.

For the nonlinear column element, the element behavior derives entirely from the constitutive laws of the fiber material. The accuracy of the analytical results depends therefore on the accuracy of the material models. For CFST column, only two material models are required: one for concrete and the other for steel tube, if the bond-slip effect is neglected.

For the materials properties in the OPENSEES, uniaxial Materal Steel02, uniaxial Giuffre Mennegotto-Pinto steel model with isotropic strain hardening, is adopted for simulating steel tube. The Concrete01 material, which is used for constructing a uniaxial Kent-Scott-Park concrete material object with degraded linear unloading/reloading stiffness and no tensile strength, is adopted for simulating the concrete.

The Young's modulus of (E_{cc}), compressive strength (f_{ck}), Poisson's ratio (μ) and tensile strength (f_{tk}) of confined concrete are taken from GB50010 [12]. The Young's modulus of (E_s), yield stress (f_y), Poisson's ratio (μ) and ultimate stress (f_u) of steel are taken from GB50017 [13].

Boundary conditions were enforce with displacement $\delta x = \delta y = \delta z = 0$ on the bottom end. The top end of the column is free, allowing displacement to take place in all directions. The constant compressive loading in axial direction is applied on the top of column. The constant force is taken as the 15% of the nominal axial capacity of the CFST column. Lateral load is applied on the top column. Figure 4 shows the controlled loading protocol. The base shear and the top displacement is monitored.

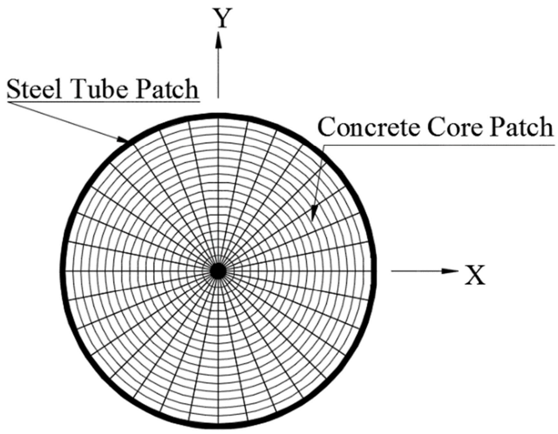


Figure 2. *Fibre Section in OPENSEES.*

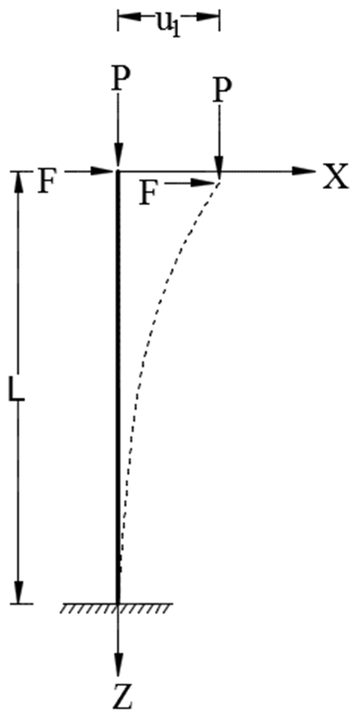


Figure 3. *Cantilever column model.*

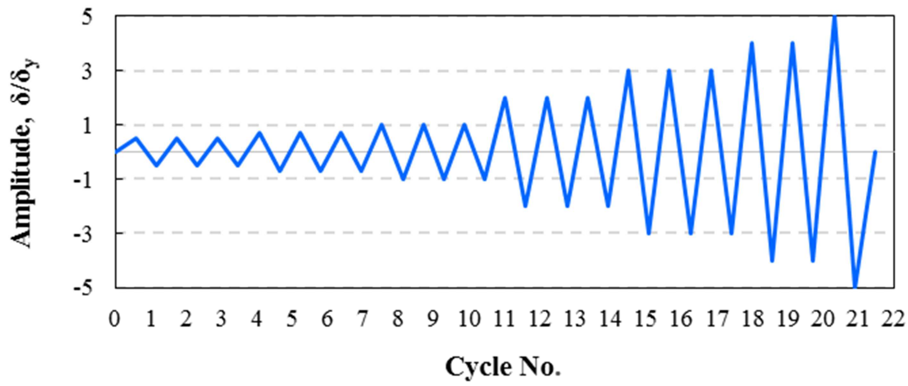


Figure 4. *Loading Protocol.*

3. Parametric Study

Numerous experimental and analytical studies have been conducted to know the seismic behaviour of CFST columns with various sectional shapes, such as circular section [14-16], rectangular section [17-19], T shaped section [17], double skin section [120] and parametric study circular section [21]. They concluded that, the hysteretic behaviour of CFST column is affected by the diameter to thickness ratio (d/t), steel yield strength (f_y), concrete compressive strength (f_{ck}), axial compression ratio (n) and slenderness ratio, for circular section and also depth to breadth ratio for rectangular section. Five different parameters are considered as stated above, having 23 numbers of specimen. Details of specimen and the parameters are summarized in Table 1.

Table 1. *Details of the Specimens considered for Analysis.*

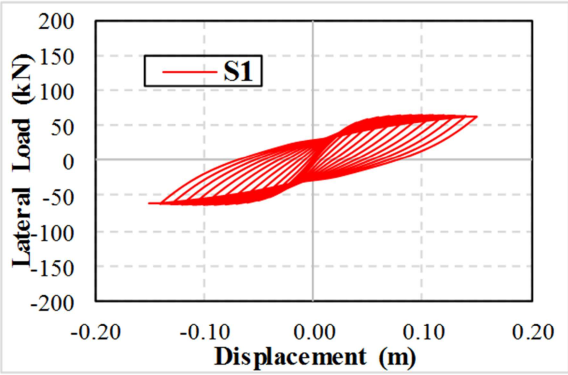
Specimen No.	Diameter (mm)	Thickness (mm)	Steel Grade	Concrete Grade	Axial Force Ratio	Height (mm)
S1	350	3	Q345	C50	0.15	3000
S2	350	4	Q345	C50	0.15	3000
S3	350	6	Q345	C50	0.15	3000
S4	350	8	Q345	C50	0.15	3000
S5	350	10	Q345	C50	0.15	3000
S6	350	12	Q345	C50	0.15	3000
S7	350	14	Q345	C50	0.15	3000
S8	350	4	Q235	C50	0.15	3000
S9	350	4	Q390	C50	0.15	3000
S10	350	4	Q420	C50	0.15	3000
S11	350	4	Q345	C30	0.15	3000
S12	350	4	Q345	C40	0.15	3000
S13	350	4	Q345	C60	0.15	3000
S14	350	4	Q345	C70	0.15	3000
S15	350	4	Q345	C50	0.00	3000
S16	350	4	Q345	C50	0.10	3000
S17	350	4	Q345	C50	0.20	3000
S18	350	4	Q345	C50	0.30	3000
S19	350	4	Q345	C50	0.40	3000
S20	350	4	Q345	C50	0.50	3000
S21	350	4	Q345	C50	0.15	1000
S22	350	4	Q345	C50	0.15	2000
S23	350	4	Q345	C50	0.15	4000

4. Results and Discussions

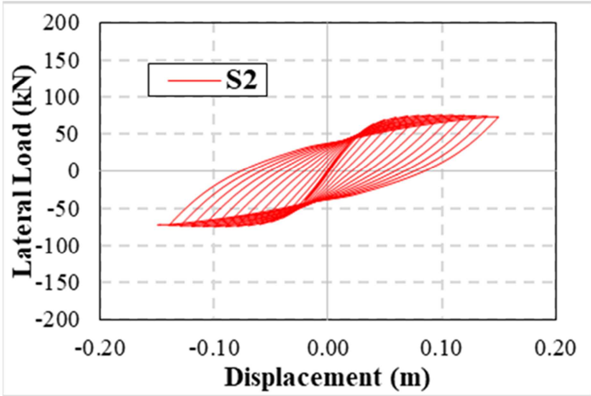
Numerical analysis of CFST columns were done using OpenSEES. The effect of different parameters on the seismic behaviour of CFST columns are illustrated below:

4.1. Diameter to Thickness Ratio

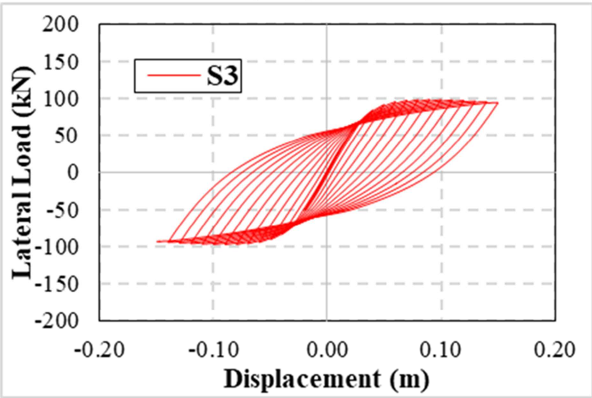
This study is conducted on five circular CFST columns to investigate the effect of thickness variation on the performance of column. The increase in D/t ratio may be either due to the increase in diameter or due to the decrease in thickness of the section. Hence it is analyzed by keeping the diameter constant and varying the thickness. For this study the D/t ratio is ranging from 25 to 116.7. The increase in D/t ratio with increased thickness for a constant diameter represents the improvement in cross section of the steel tube and hence produces greater section capacity. The comparison of hysteresis behaviour of the five different D/t ratio is shown in figure 5 (S1-S7).



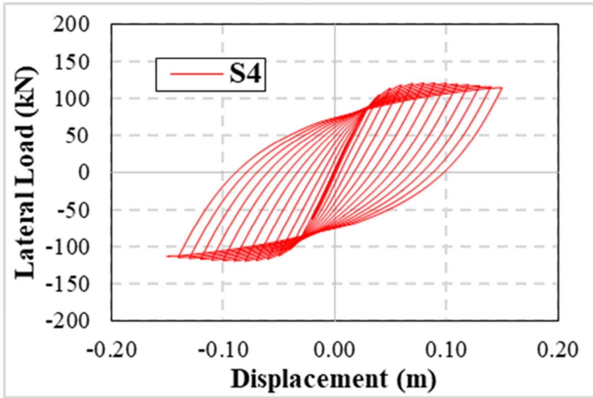
a) Specimen 1



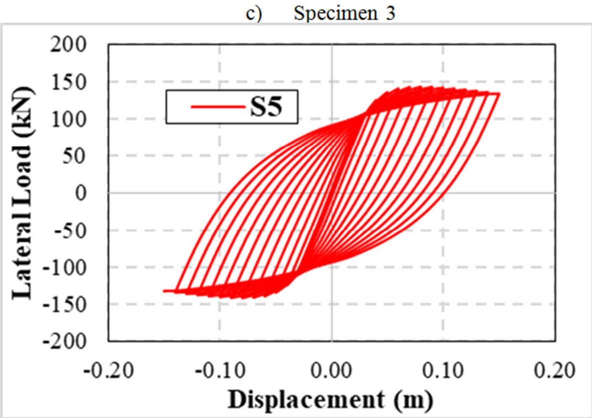
b) Specimen 2



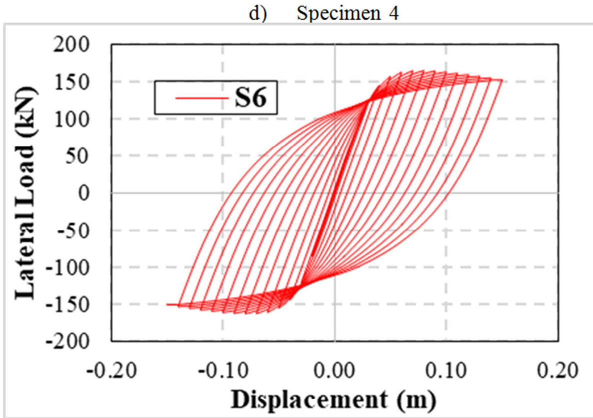
c) Specimen 3



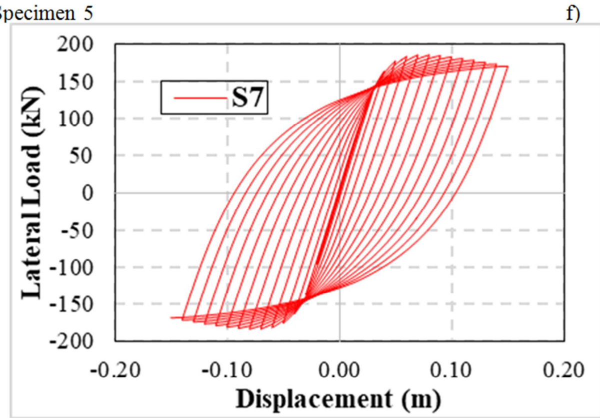
d) Specimen 4



e) Specimen 5



f) Specimen 6



Specimen 7

Figure 5. *Load–displacement hysteresis curves for different D/t ratio.*

Figure 6 shows the P-Δ curves for different D/t ratio. The results suggest that the cyclic lateral load capacity of a CFST column can be significantly increased by using a smaller D/t ratio for the cross-section in the design. When the D/t ratio is increased from 25 to 116.7, the ultimate cyclic lateral load of the column is found to decrease by 190.447%.

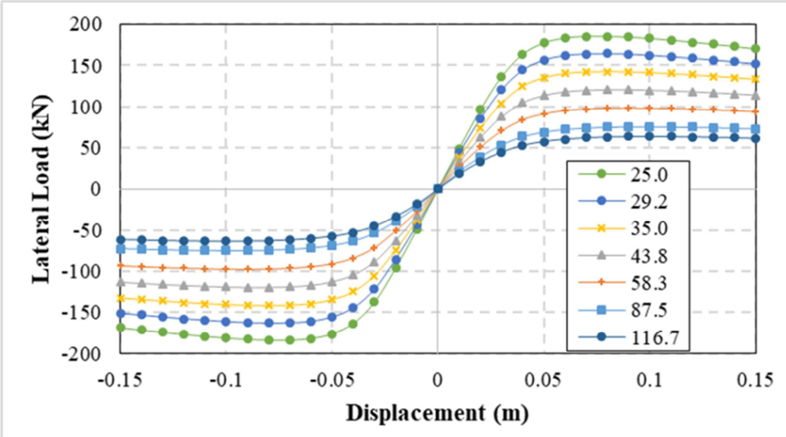


Figure 6. *Skeleton curves for different D/t ratio.*

4.2. Grade of Steel

Four circular CFST columns were taken to investigate the effect of grade variation of steel grade on the performances of CFST column. The capacity of CFST column is decided by the yield strength of steel. The capacity of CFST column linearly increases with the increase in the steel grade. Figure 7 (S2, S8-S10) gives the cyclic lateral load-deflection curves for CFST columns with different steel yield strengths. The ultimate cyclic lateral load of columns is found to increase significantly with an increase in the steel yield strength.

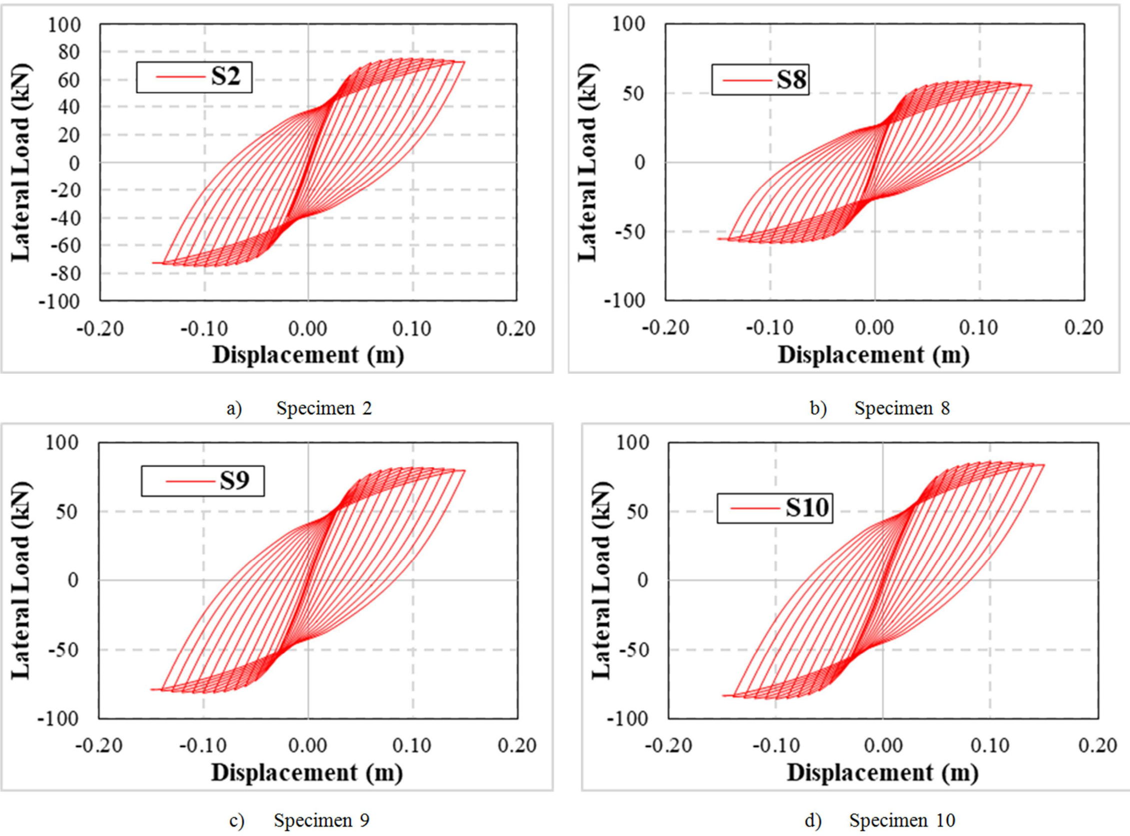


Figure 7. *Load–displacement hysteresis curves for different Grade of Steel.*

Figure 8 shows the P-Δ curves for different grade of steel. It can be observed from figure that the steel yield strength does not have an effect on the initial flexural stiffness of the columns. By increasing the steel yield strength from 235 MPa to 420 MPa, the ultimate cyclic lateral load of the column is found to increase by 45.76%.

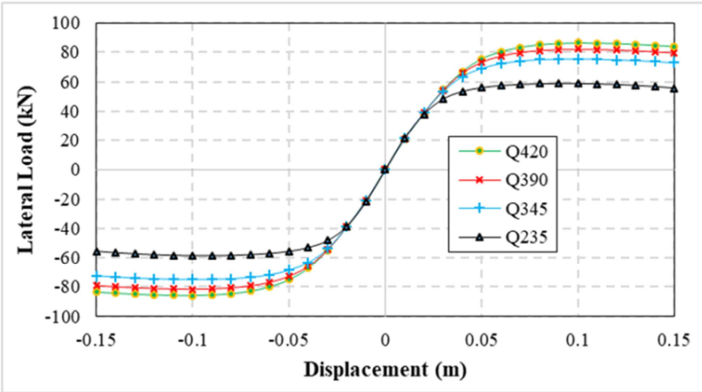


Figure 8. *Skeleton curves for different Grade of Steel.*

4.3. Grade of Concrete

Five circular CFST columns were taken to investigate the effect of variation of concrete on the performances of CFST column. The strength of concrete core decides stiffness of CFST columns. Stiffness increases with increase in concrete strength but columns fail due to crushing of concrete exhibiting brittle behavior when filled with high strength concrete. But it is a fact that increase in concrete core strength increases the strength of filled columns to a larger extent, no matter of either D/t ratio or L/D ratio. The computed cyclic load-deflection curves for CFST columns with different concrete compressive strengths are depicted in Figure 9 (S2, S11-S14). The ultimate cyclic lateral loads of CFST columns increase with an increase in the concrete compressive strength.

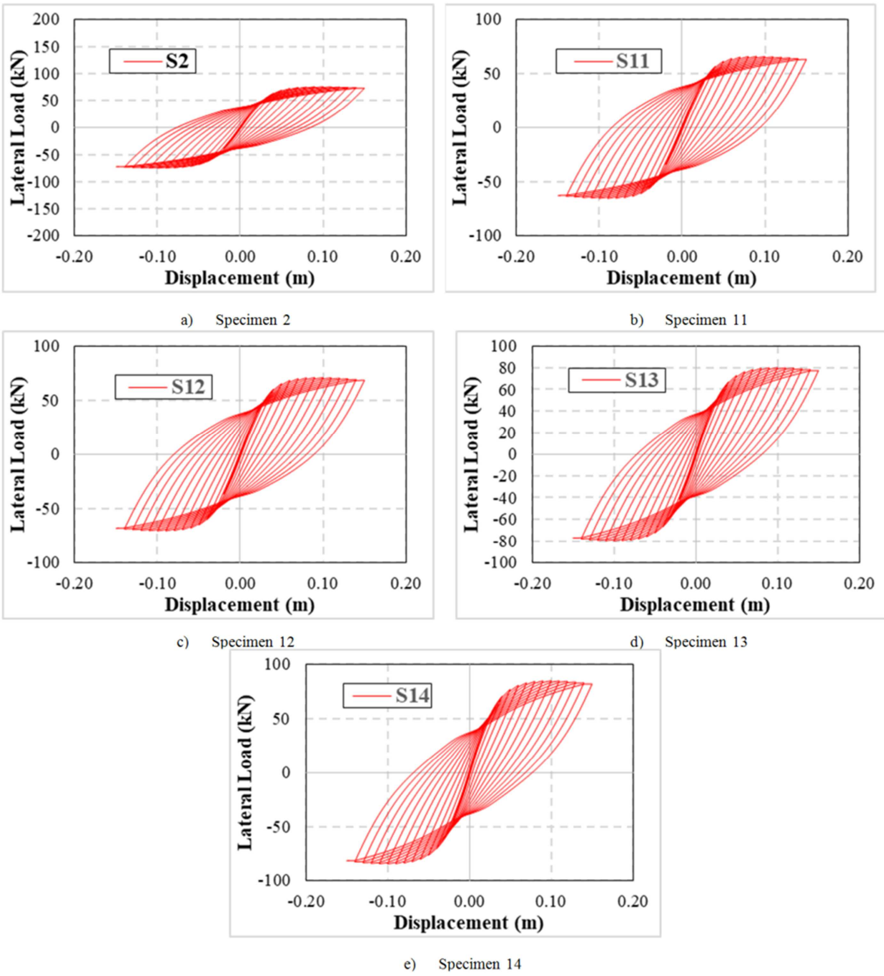


Figure 9. *Load–displacement hysteresis curves for different Grade of Concrete.*

Figure 10 shows the P-Δ curves for different grade of concrete. The initial flexural stiffness of the columns has a slight increase due to the use of higher strength concrete. The results indicate that the use of high strength concrete will not lead to significant increase in the cyclic lateral load capacity and flexural stiffness. By increasing the concrete compressive strength from 30 MPa to 70 MPa, the ultimate cyclic lateral strength is found to increase by 28.78%.

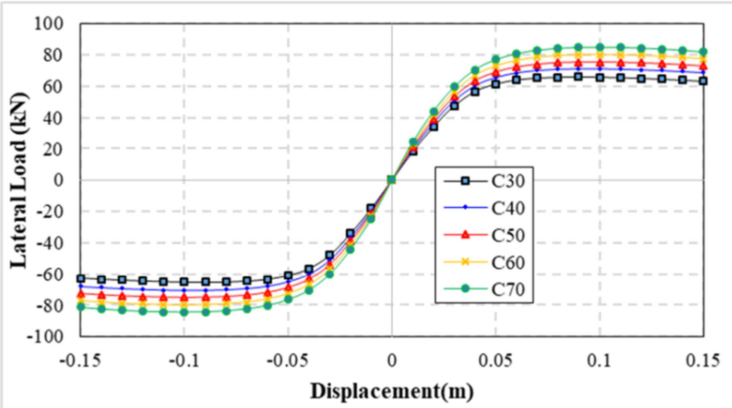
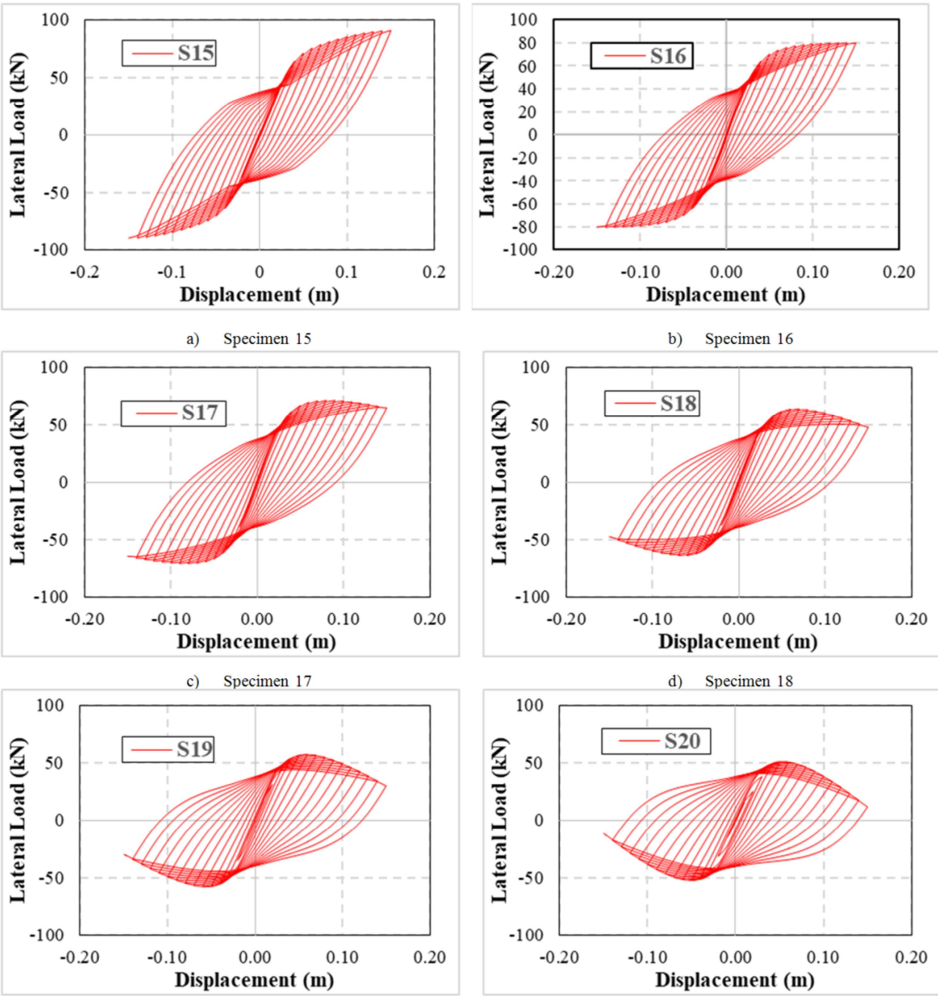


Figure 10. *Load–displacement hysteresis curves for different Grade of Concrete.*

4.4. Axial Force Ratio

This study is conducted using the model on five circular CFST columns to investigate the effect of grade variation of concrete on the performances of CFST column. If the axial forces ratio increases, it has not such significant effect on the ultimate load carrying capacity. The increase in the axial load the overall stiffness decreases due to P-delta effect on the CFST column. Figure 11 (S15-S20) shows the effects of axial force ration on the lateral load carrying capacity of CFST columns. Thea axial load ratio varying from 0 to 0.5.



a) Specimen 15 b) Specimen 16

c) Specimen 17 d) Specimen 18

e) Specimen 19 f) Specimen 20

Figure 11. *Load–displacement hysteresis curves for different Axial Force Ratio.*

Figure 12 shows the P-Δ curves for different Axial Force Ratio. From the figure it is observed that there is no change in the initial stiffness but the ultimate loading carrying capacity decreases with increase in axial force ratio. Increase in the axial force ratio from 0 to 50% the lateral load carrying capacity of CFST columns is decreased by 43.95%.

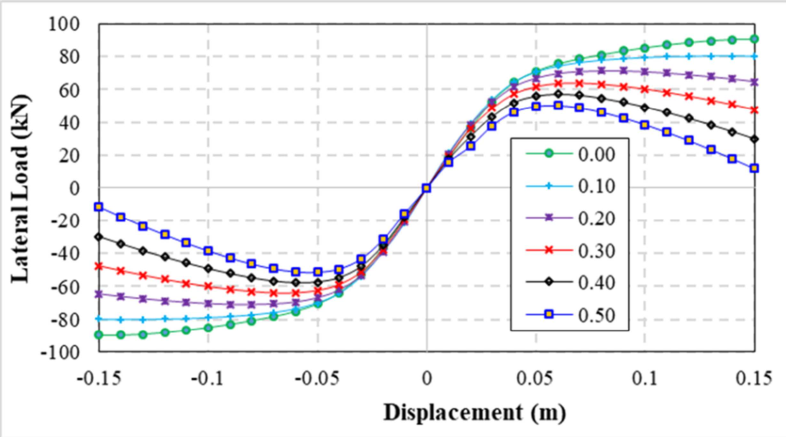


Figure 12. *Load–displacement hysteresis curves for different Axial Force Ratio.*

4.5. Slenderness Ratio

This study is conducted using the model on five circular CFST columns to investigate the effect of grade variation of concrete on the performances of CFST column. The length to diameter ratio (Le/r) represents the slenderness of the column. The failure modes of CFST columns are characterized by yielding of steel followed by crushing of concrete. The strength increase will occur only for columns of smaller slenderness ratio (or L_e/r ratio). Columns with greater slenderness ratio fail by overall buckling. Hence it can be observed from the analytical results that the decrease in L_e/r ratio increases the section capacity of the CFST column. The slenderness ratio is considered from 11.4 to 68.6 for this study. The hysteresis curves (S2, S21-S23) of different slenderness ratios are shown in figure 13.

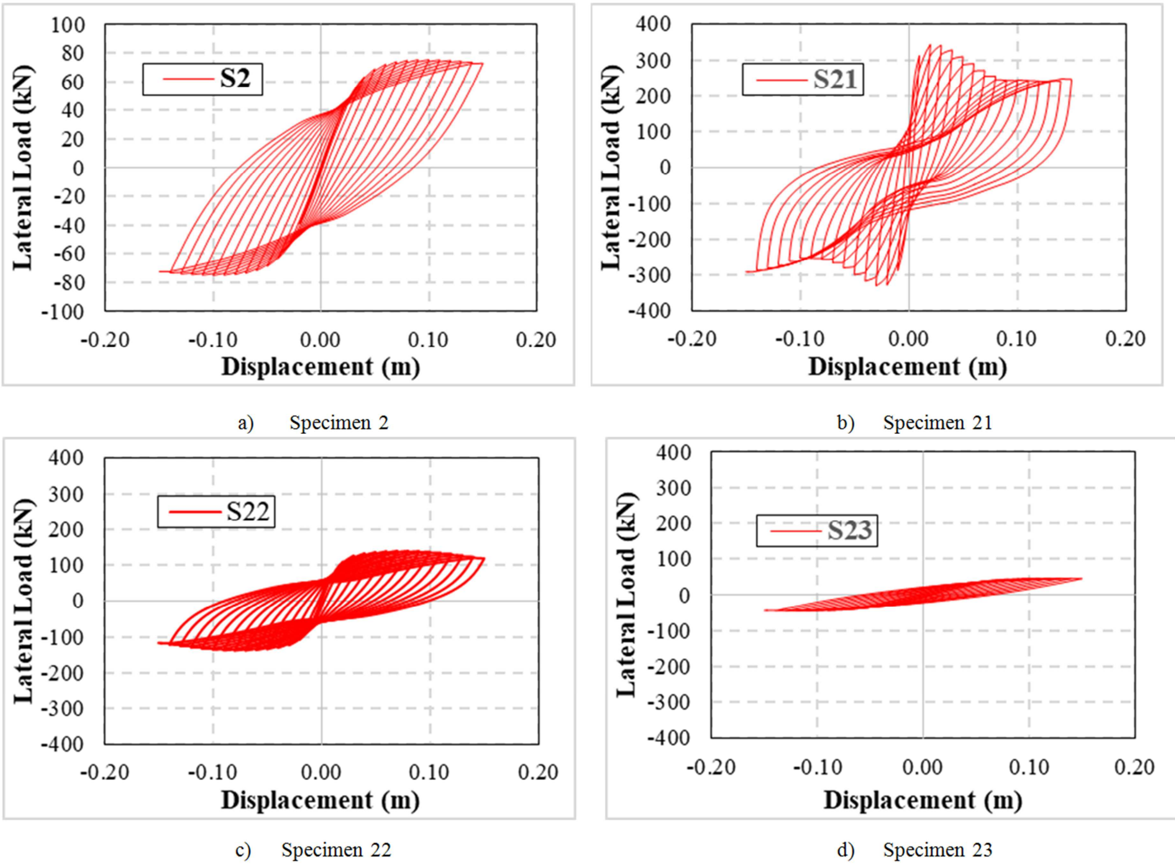


Figure 13. *Load–displacement hysteresis curves for different Slenderness Ratio.*

Figure 14 shows the P-Δ curves for different Slenderness Ratio. The skeleton curve shows that the less slenderness ratio having high lateral load capacity but low ductility while the more slenderness ratio having low lateral load capacity but high ductility. When increasing the column slenderness ratio from 11.4 to 45.7, the ultimate cyclic lateral load of the slender column decreases by 86.6%.

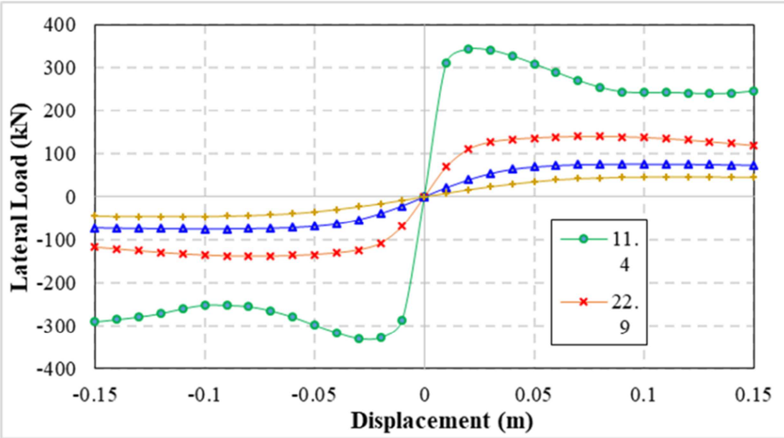


Figure 14. *Load–displacement hysteresis curves for different Slenderness Ratio.*

5. Conclusions

This paper has presented a numerical model for the nonlinear inelastic analysis of thin-walled circular CFST columns under constant axial load and cyclically varying lateral loading. Based on the parametric study, the following important conclusions are drawn:

a) lateral load carrying capacity of a CFST column can be significantly increased by a smaller D/t ratio for the cross-section in the design.

b) The steel yield strength does not have an effect on the initial flexural stiffness of the columns. However, the ultimate lateral load of columns is found to increase significantly with an increase in the steel yield strength.

c) The initial flexural stiffness of the columns has a slight increase due to the use of higher strength concrete. The results indicate that the use of high strength concrete will not lead to significant increase in the lateral load capacity and flexural stiffness.

d) There is no change in the initial stiffness but the ultimate loading carrying capacity decreases with increase in axial force ratio.

e) The lateral deflection at the ultimate lateral load of the columns increases with increasing the column slenderness ratio and ultimate lateral load capacity of the columns decreases with increasing the column slenderness ratio.

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