Effect of dimensional parameters on the seismic performance of circular CFST columns

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Abstract. Due to the expansion of cities and increase in population, the need for construction of high rise buildings becomes more essential in the society. As earthquakes are of the greatest damaging natural hazards to the buildings, the design and construction of structures which are capable of resisting the adverse effects of earthquakes become necessary. Concrete Filled Steel Tubes (CFSTs) are the steel tubular sections in-filled with concrete and with a composite action. CFSTs are becoming a popular solution for structures located in seismic areas, due to their high strength, excellent ductility and large energy absorption capacity. This study was mainly concentrated to find out the effect of dimensional parameters on the seismic performance of CFSTs. Width- thickness ratio (D/t) and slenderness ratio (L/D) were taken as two parameters and the study was carried out using circular CFST buildings. It was observed that, there will be a particular limit for D/t and L/D ratio upto which the thickness and diameter of the CFSTs can be decreased. At that point the building will show a better seismic performance.

1. Introduction
Concrete-filled steel tubes (CFST) are composite structures of steel tube and in-filled concrete. Concrete filled steel tubular member uses the advantages of both steel and concrete. They comprise of two main parts, an outer steel hollow section of circular or rectangular shape and an inner filler material of plain or reinforced concrete. A CFST member consisting of a steel tube which is filled with concrete material realizes the importance of steel reinforcement to provide confinement for the concrete and to increase the load-carrying capacity of the composite member. From the structural point of view, the inner concrete material not only prevents the occurrence of inward buckling of the outer steel tube but also enhances the ductility of the CFST member up to the ultimate load. CFST member performs under composite action, ie both the steel and concrete will resist the external loading by interacting together by bond and friction action. In a CFST member, concrete and steel are combined together in such a fashion that the advantages from both the materials should be effectively utilized.

First research on CFST members was started by 20th century which mainly concentrated on strength capacity. Application of CFST concept can lead to the reduction in total consumption of steel and thereby can reduce the overall construction cost for the building compared to the conventional structural steel system. CFST members can be used in multi-storey buildings as both columns and beams and also as bridge piers. Concrete core enhances higher compressive strength, stiffness and damping whereas tensile strength is provided by the outer steel tube. Also high strength CFST columns require only smaller cross-sections compared to the conventional reinforced cement concrete columns under the same loading conditions. The behavior of CFST members in bending, shear, compression and fatigue resistance are also superior over reinforced members under cyclic seismic loading. The steel concrete composite columns
have several advantages such as high axial load carrying capacity, good ductility performance, energy absorption capacity and high fire resistance as well as fast construction [1].

In this study the effect of dimensional parameters on the seismic performance of CFSTs were evaluated. Width- thickness ratio ($D/t$) and slenderness ratio ($L/D$) were considered as two parameters for the study. ETABS- 2018 software was used for the design and analysis and the columns of the building were chosen to be circular CFSTs.

2. Modeling and analysis
The plan of the building was fixed to be in rectangular shape having dimension of 25m x 20m with the longest side along the X- axis. The spacing of each column was fixed as 5m and the number of bays provided along X and Y directions were 5 and 4 respectively. G+12 storey buildings were used by fixing each storey height as 3m, obtaining an overall height of 39m. Usually pile foundations are used for high rise buildings and here also the support conditions are chosen to be fixed. The detailed plan of the building was given in Figure 1. The material needed for the CFST members were fixed to be Fe345, for the outer structural steel and M30, for the inside concrete. Floors and roofs were modeled using RCC slab with a fixed thickness of 150mm.

Three types of loads were considered for the analysis. They are dead loads, live loads and seismic loads. For the roofs and floors, the dead and live loads were applied separately. Dead loads were applied as frame loads with a value of 6 kN/m and 12 kN/m on roofs and floors respectively. Live load of 1.5 kN/m$^2$ was applied on roofs and 3 kN/m$^2$ was assigned for floors, by considering them as the shell loads. Seismic loads on the building were calculated according to the Indian standard code, IS 1893: 2016. Loads were applied both in X and Y directions without considering eccentricities. The details of the seismic characteristics used for the study were shown in the Table 1.

Since there is no particular code for the design of CFSTs in India, the American Standard code, AISC 360-10 was used for the design of the building. The beams of the buildings were modeled using the steel I-section, ISMB 300. With all the details, building was modeled using ETABS-2018 software and seismic analysis was carried out using linear dynamic analysis. Circular CFST columns having dimensions 450mm x 12mm was obtained from the design, for which the thickness and diameter were varied and analysis were carried out separately to find out the effect of dimensional parameters under seismic loads.
Table 1. Details of seismic load characteristics.

| Seismic characteristics          |  
|----------------------------------|
| Design Code                      | IS 1893: 2016  
| Soil Type                        | II (Medium Soil)  
| Seismic Zone                     | III  
| Seismic Zone Factor              | 0.16  
| Importance Factor                | 1.5  
| Response Reduciton Factor        | 5  
| Damping Ratio                    | 0.05  
| Modal Combination                | CQC  
| Directional Combination Type     | SRSS  

2.1. Width- thickness ratio (D/t)

Width- thickness ratio is one of the main parameters to understand the behavior of CFSTs. Here the study of this parameter was conducted by varying the thickness of CFSTs for that already designed circular column (450mm x 12mm) building as 6mm, 8mm, 10mm and 14mm. The diameter for each circular CFSTs were fixed as 450mm itself. The dimension of CFST columns used for each building and their D/t ratios are shown in the Table 2.

Table 2. Dimensions of circular CFSTs for each D/t ratios.

| Building No | Dimensions of circular CFSTs | D/t ratio |
|-------------|-------------------------------|-----------|
| 1           | 450mm x 6mm                   | 75        |
| 2           | 450mm x 8mm                   | 56.25     |
| 3           | 450mm x 10mm                  | 45        |
| 4           | 450mm x 12mm                  | 37.5      |
| 5           | 450mm x 14mm                  | 32.14     |

2.2. Slenderness ratio (L/D)

Slenderness ratio is calculated as the length to width ratio. In this study circular CFST columns were considered and hence length to diameter ratio (L/D) was taken as the parameter by varying the diameters of the columns. For this to be done, the designed circular column CFST building with column size 450mm x 12mm was considered. Length and thickness of CFSTs were remained as same and only the diameter of the columns were varied from 350mm to 550mm. Table III shows the dimensions of the CFST columns used for the five buildings which were taken for the study and the corresponding L/D ratios.
Table 3. Dimensions of circular CFSTs for each L/D ratios.

| Building No | Dimensions of CFST columns | Length of columns | L/D ratio |
|-------------|----------------------------|------------------|-----------|
| 1           | 350mm x 12mm               | 3000mm           | 8.57      |
| 2           | 400mm x 12mm               | 3000mm           | 7.5       |
| 3           | 450mm x 12mm               | 3000mm           | 6.67      |
| 4           | 500mm x 12mm               | 3000mm           | 6         |
| 5           | 550mm x 12mm               | 3000mm           | 5.45      |

3. Results and discussions

The thickness and diameter of the CFST were varied and for each building seismic analysis was carried out by using linear dynamic method. Fundamental time periods, storey displacements, storey drifts and base shears were the seismic parameters considered for the comparative study. The results obtained from the study are discussed here.

3.1. Effect of width-thickness ratio (D/t)

The time period values obtained for each building with different D/t ratios were illustrated in the Figure 2. Maximum value of time period was shown by the lowest thick CFST building ie, by the 450mm x 6mm CFST building and also it was observed that while increasing the thickness of the CFSTs, the time periods start decreasing upto 12mm thickness and after that gets increasing. Total 6 modes were considered for the study and for every mode the same pattern of variation in time periods was observed.

Figure 2. Fundamental time periods (Seconds).

Maximum displacements obtained by the response spectrum analysis for each floors for the different CFST buildings along X and Y directions were shown in the Figure 3 (a) and (b) respectively. From the pattern of variation of the graphs, it is found that the displacements at each floor starts decreases from the 6mm thick CFST to the 12mm thick CFST and thereafter increases for the 14mm thick CFST building.
The graphs obtained for storey drifts for the different CFST buildings were shown in Figure 4. From the graph it can be observed that for the bottom most stories 6mm thick CFST building shows higher storey drifts and continues the decreasing pattern giving lowest value for 14mm thick CFST building. But while moving to the top stories the pattern of variation starts changing by giving deceasing values of storey drifts from 6mm to 12mm and after that a higher value for 14mm thick CFST. The same variation was observed for both the axes. From this graphs it is clear that for the lower storey buildings higher thick CFST will cause low storey drifts whereas when increasing the number of stories in the building there will be a limit for the thickness of CFST beyond which can lead to high storey drifts.

Table 4 shows the base shears obtained for the buildings with different D/t ratios. For along both the X and Y directions it is observed that increase in thickness of CFST causes increase in base shears also, i.e. here the building with 6mm thick CFST gave lowest base shears and with 14mm thick CFST showed highest base shears for both the axes.
Table 4. Base shears along X and Y axes.

| Building Type | Base shear (kN) | X- axis | Y- axis |
|---------------|----------------|---------|---------|
| 450X6         |                | 646.4724 | 639.6522 |
| 450X8         |                | 654.2699 | 647.5332 |
| 450X10        |                | 661.0347 | 654.4106 |
| 450X12        |                | 666.2838 | 660.1835 |
| 450X14        |                | 672.3353 | 666.0142 |

3.2. Effect of slenderness ratio (L/D)

Time periods obtained for the buildings upto 6 modes were shown in the Figure 5. It was observed that when diameter of the CFST increases time periods start decreasing, ie highest value of time period was shown by the 350mm diameter CFST building whereas lowest value was given by the 550mm diameter CFST building. The building with higher L/D ratio gave the higher time period and lower L/D ratio showed the lower time period value for every mode.

Figure 5. Fundamental time periods (Seconds).

Storey displacements were found to be higher for the building with lower diameter CFST columns, ie increase in diameter of CFST leads to decrease in displacements. This can be clearly observed from the Figure 6, which represents the storey displacements obtained for each building having different L/D ratios. The building with higher L/D ratio gave higher displacements and with lower L/D ratio showed lower displacements. The same pattern of variation was observed for both the directions.

For bottom stories upto 7th floor 350mm diameter CFST building showed highest storey drifts and gave a decreasing pattern of variation from 350mm diameter CFST to 550mm diameter CFST building. Whereas from the 8th floor to 12th floor, the decreasing pattern was shown upto 450mm diameter CFST and after that increase in storey drifts were observed upto 550mm diameter CFST building. But for the top most storey, the condition was totally reversed compared to bottom most stories. ie the highest storey drift was given by the 550mm diameter CFST and lowest value was shown by the 350mm diameter CFST building. The same pattern of variation was observed for both the directions. Figure 7 illustrates the variation of storey drifts observed for the buildings having different L/D ratios along both the X and Y
axes. From the study it can be given that for low storey buildings, increase in diameter of CFST, ie low values of L/D ratios can decrease the storey drifts. But when the number of stories increases that can give a reverse result.

![Figure 6. Maximum storey displacements along X-axis (a) and along Y-axis (b).](image)

![Figure 7. Maximum storey drifts along X-axis (a) and along Y-axis (b).](image)

Table 5 represents the maximum storey shear obtained at the base for each building. It is clear from the table that, as the diameter of the CFST increases the base shear of the building also increases, ie the highest base shear was given by the 550mm diameter CFST building whereas lowest base shear was observed for the 350mm diameter CFST building. In terms of L/D ratio, it can be stated that as the L/D ratio decreases, base shear starts increasing.
Table 5. Base shears along X and Y axes.

| Building Type | Base shear (kN) |       |       |
|---------------|----------------|-------|-------|
|               | X- axis        | Y- axis |
| 350x12        | 604.7761       | 599.2981 |
| 400x12        | 638.9634       | 632.2069 |
| 450x12        | 666.2838       | 660.1835 |
| 500x12        | 692.1746       | 686.0971 |
| 550x12        | 716.2297       | 710.4688 |

4. Summary

When considering the D/t ratios, it was observed that time periods and storey displacements of the buildings give higher values for 6mm thick CFST and then starts decreasing up to 12mm thick CFST and thereafter again increases for the 14mm thick CFST building. So it can be given that there will be a particular limit for D/t ratio at which the time periods and storey displacements will be minimum. The increase in thickness of CFST can improve the behavior of steel in the building and can lead to high lateral displacements due to the increase in flexibility. So there have to keep a limit for thickness up to which thickness can be reduced to get a better performance. For bottom stories, storey drifts were found to be higher for 6mm thick CFST building or the building with higher D/t ratio and then showed a decreasing pattern up to the 14mm thick CFST building or the building with lower D/t ratio. But when moving to the upper stories, decrease in storey drifts were found from 6mm thick CFST to 12mm thick CFST and thereafter increased for 14mm thick CFST building. Therefore the storey drifts will be decreasing up to a particular limit of D/t ratio. In this study D/t ratio of 37.5 was found to be the limiting value of D/t ratio at which the time periods, storey displacements and storey drifts were found to be minimum. Base shears were observed to be increasing with the increase in thickness of CFSTs, ie with the decrease in D/t ratios.

As with the decrease in L/D ratio, it was observed that time periods and storey displacements starts also decreasing, ie when the diameter changes from 350mm to 550mm the time periods and displacements starts decreasing giving lowest value for the 550mm diameter CFST building. When the diameter of CFST increases, the concrete content in the CFST also starts increasing thereby building behaves like an RCC building, ie stiffness of the building also increases giving low lateral displacements. For bottom stories storey drifts were found to be decreasing as with the decrease in L/D ratios. But when considering the top stories, there shows a particular limit of L/D ratio up to which the storey drifts decreases and after that increases. This was observed only upto 12th floor, whereas for the top most storey, ie the 13th storey, a continuous increasing pattern was observed from 350mm diameter to 550mm diameter CFST building. So it can be said that for higher storey buildings there has to keep a limit for L/D ratio below or beyond which structure can cause least performance under seismic loads. From this study, it was observed that at an L/D ratio of 6.67, the building shows better seismic performance. Base shears were found to be increasing with the decrease in L/D ratios due to the increase in weight of the buildings.

5. Conclusions

The effect of the dimensional parameters on the performance of CFSTs was evaluated by using the width-thickness ratio (D/t) and slenderness ratio (L/D). The study was carried out by varying the thickness and diameters of the circular CFSTs. It was observed that there will be a particular limit for D/t ratio, at which the building will show a good seismic performance. Decrease in D/t ratio causes decrease in time periods, storey displacements and storey drifts and after a particular limit of D/t ratio, they starts again increasing, ie increase in thickness of CFST can only be provided up to a particular limit. D/t ratio of 37.5 was
obtained as the limiting value from the study. Above this ratio, there will be less confinement effect for the concrete due to less thickness of outer steel tube and below that ratio higher thickness of CFST will cause the steel behavior of the building to become more prominent. Both the conditions lead to less seismic performance and so there has to keep a limiting thickness or D/t ratio for attaining better performance of the building under seismic loads. Decrease in slenderness ratio, L/D ratio or the increase in diameter of CFST leads to the decrease in time periods and storey displacements. Storey drifts were found to be decreasing upto a limit of L/D ratio and after that starts again increasing. The building having L/D ratio of 6.67 was found to be better under seismic loads. Increase in thickness and diameter of CFSTs can cause the improvement in the behavior of CFSTs as steel and RCC respectively. So when considering the dimensions of CFSTs, there has to keep a limit for thickness and diameter of CFSTs or for the D/t and L/D ratios, below or beyond which can cause least performance under seismic loads.

6. References

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