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# EXPERIMENTAL ANALYSIS OF AXIALLY LOADED INFILLED COLUMNS OVER RC COLUMN

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**ABSTRACT -** This paper investigates the behavior of axial load over concrete-filled steel tube (CFST) column and conventional reinforced concrete (RC) column. The comparative study show that the difference of the axial load capacity and failure pattern for both of the concrete-filled steel tube (CFST) and reinforced concrete (RC) columns. The experimental results and results obtained from extended three dimensional building system (ETABS) software is used for study. Concrete-filled steel tube (CFST) column with varying size and conventional reinforced concrete (RC) column were tested for better optimization of column. The experimental results shows that the concrete-filled steel tube (CFST) column has a higher bearing capacity, more effective plastic behaviour and greater stiffness.

**Keywords : CFST Column, RCC Column, ETABS.**

## 1. INTRODUCTION

In residential systems where land cost is at a premium, any savings in floor area will be of considerable advantage both in terms of cost of the construction of floor and better utilization of materials. With this in view, some of the innovations which are prevalent in the basement floors for parking purpose in order to overcome land / space scarcity, are use of steel in columns for reduction in area compared to concrete and use of steel-concrete composites offsetting some of the costs in using steel completely. Generally columns in high rise buildings are larger in size when concrete is used and occupy more space cutting into the floor / carpet area of the apartment resulting in more cost. Concrete Filled Steel Tubular (CFST) composite columns represent a class of structural systems, where the best properties of steel and concrete are used to their maximum advantage. When employed under favourable conditions the steel casing confines the core tri-axially creating a confinement for better seismic resistance and the in-filled concrete inhibits the local buckling.

Square Concrete Filled Steel Tubes (SCFST) and Circular Concrete Filled Steel Tubes (CCFST) are being used widely in real civil engineering projects due to their excellent static and earthquake resistant properties, such as high strength, high ductility and large energy absorption capacity. Concrete Filled Steel Tubes (CFST) are also used extensively in other modern civil engineering applications. When they are used as structural columns, especially in high-rise buildings, the composite members may subjected to high shearing force as well as moments under wind or seismic actions. It may be noted here that mechanical and economic benefits can be achieved if CFST columns are constructed taking advantages of high-strength materials. For example, high-strength concrete infill contributes greater damping and stiffness to CFST columns compare to normal strength concrete. Moreover, high-strength CFST columns require a smaller cross-section to withstand the load, which is appreciated by architects and building engineers. New developments, including the use of high strength concrete and the credit of the enhanced local buckling capacity of the steel has allowed much more economical designs to evolve. The main economy achieved by using high strength concrete in thin steel casings is that the structural steel cost is minimized and the majority of the load in compression is resisted by the high strength concrete .However, bare steel or reinforced concrete columns are still used more extensively than CFST columns due to the lack of knowledge and experience that Engineers have with CFST structural systems.

## 1.1 COMPOSITE CONSTRUCTION

In composite construction, the bare steel sections support the initial construction loads, including the weight of structure during construction. Concrete is later cast around the steel sections, or filled inside the tubular sections. The concrete and steel are combined in such a combination that the advantages of both the materials are utilized effectively in composite column. The lighter weight and higher strength of steel permit the use of smaller and lighter foundations. The subsequent concrete addition enables the building frame to easily limit the sway and lateral deflections.

No additional reinforcing steel is required for CFST columns except for requirements of fire protection to stanchions in steel framed buildings. Since the columns are subjected mainly to axial loads, the transverse shear (change in bending moment along the length) is much lower. Therefore the mechanical shear connectors are normally not required to develop complete interaction in composite columns. The use of round, square and rectangular steel tubular columns is becoming popular for high-rise structures and they are also of special interest to the architects from an aesthetic view point and to the engineers from a structural effectiveness view point.

The general term 'Composite Column' refers to any compression member in which a steel element acts compositely with the concrete element, so that both elements resist compressive forces. In other words by definition a steel-concrete column is a member with a cross section consisting of a steel section (or sections) and concrete which act together to resist axial compression. There is a wide variety of column types of various cross sections, but only two common types of composite column are in use. A steel concrete composite column is a compression member comprising either of a concrete encased steel section or a concrete filled steel tubular section (CFST) and is generally used as a load-bearing member in a composite framed structure. Figure 1.1 shows two typical cross-sections of concrete filled steel tubular sections. Note that there is no requirement to provide additional reinforcing steel for composite concrete filled steel tubular sections, except for requirements of fire resistance where appropriate.

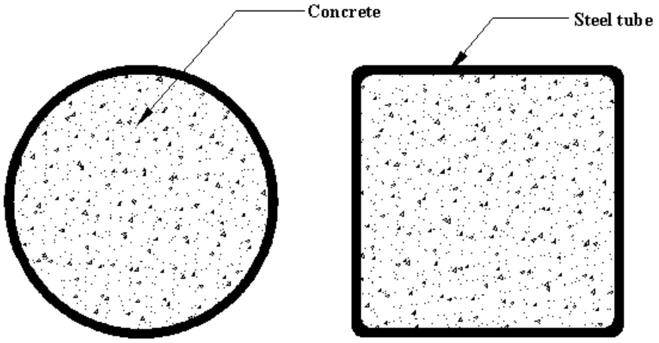

**Figure 1** Typical Cross-Sections Of Concrete Filled Steel Tubular Sections

In a composite column, both the steel and concrete would resist the external loading by interacting together by bond and friction. Supplementary reinforcement in the concrete encasement prevents excessive spalling of concrete both under normal load and fire conditions. The steel tube provides tri-axial confinement which is same as that provided by stirrups in reinforced concrete columns. Hence, CFST columns reduce the amount of expensive steel required to support the given load substantially, while the dimensions of the column are smaller than those of a reinforced cement concrete column of the same strength there by increasing the available floor space.

## 1.2 APPLICATIONS OF COMPOSITE COLUMNS

Composite columns of steel and concrete, especially in steel hollow sections filled with concrete, manifest a number of major architectural, structural and economic advantages, which are very much appreciated by modern designers and building engineers. They have been used in the structural buildings for quite a few decades, although their application has increased substantially in recent times. Some of these qualitative aspects leading to special preferences by the architects and structural people are listed below:

- The concrete filling lends to the steel hollow sections a still higher rigidity and load bearing strength, so that the aesthetic slender columns can bear higher loads without any increase in their external dimensions. This can be further enhanced by means of reinforcing bars.
- Steel allows a pretentious architectural design with various colourings. The painting costs as well as the costs for corrosion protection, eg. spray, paints, etc., are low due to small external surface area of the columns.
- There is seldom any problem with respect to the joints due to the highly developed assembly technique in structural engineering today. This permits prefabrication in workshop and a quick and dry assembly on site.

The composite column has higher ductility than the concrete column and connections may be constructed following the experience of steel constructions. The concrete filling not only leads to a bearing capacity which is much higher than that of steel columns but it also promotes resistance against fire. As far as ductility and rotation capacity are concerned, concrete filled steel tubular columns show the best seismic behaviour compared to other types of composite columns. The concrete is held by the steel profile and cannot split away even if the ultimate concrete strength is reached. The research work in the field of composite columns with concrete filled hollow sections has a long tradition in various parts of the world.

## 2. EARLIER STUDIES

**A.L. Krishan, E.A. Troshkina, E.P. Chernyshova. et. al** worked on **"Efficient Design Of Concrete Filled Steel Tube Columns"**

The calculation procedure of the bearing capacity of concrete filled steel tube columns is given here in this article. Concrete filled steel tube columns have large number of different advantages. However, it is necessary to note the main disadvantages of concrete filled steel tube columns. One of the most significant design deficiencies of traditional concrete filled steel tube columns is the practical absence of the hooped compression under operational loads due to lower values of the Poisson's ratio of concrete in comparison with steel, that is why the holder tends to break away from the concrete core in the elastic stage. It is offered to make concrete filled steel tube columns with a preliminary compressed concrete core to improve their design.

**W.H. Kang, B. Uy, Z. Tao and S. Hicks et al.** proposed **"Design Strength Of Concrete-Filled Steel Columns"**

The purpose of this paper is to recalibrate the capacity reduction factors, estimate the reliability of current equations, and investigate the effect of these factors in AS 5100.6, the Australian Bridge Standard for concrete-filled steel tubular columns. This work has important ramifications for other international codes of practice as the Australian code has the identical or similar underlying design philosophy with Euro code 4, AISC and the code of practice in Hong Kong. The method developed by Johnson and Huang is extensively applied to the Australian code format to recalibrate the capacity factors in AS 5100 for a target reliability of $\beta = 3.04$ based on an extensive database of 1,583 test results covering a wide range of input parameter values. In addition, an inverse analysis procedure based on Johnson and Huang's method is proposed to estimate the reliability of design equations with known capacity factors. The analysis results show that the interaction between the concrete and steel needs to be considered for the current capacity factors in AS 5100. The results also show that the current capacity factors provide greater reliability than the target reliability suggested in AS 5104:2005/ISO 2394:1998, but after considering the additional uncertainties created due to the application of multiple capacity factors, the reliability was almost the same as the recommended value. In conclusion, the current capacity factor values in AS 5100 are adequate with regards to safety and can be maintained, but better optimised values would be preferable to improve the cost-safety balance.

## 3. EXPERIMENTAL PROGRAM

### 3.1 Material Properties

| **Material** | **Properties** |
|---|---|
| Concrete | M20 |
| Steel Tube | FE250 |
| Steel for Reinforcement | FE500 |

### 3.2 Materials required

**Steel -** The hollow steel tube has a square cross section with the size of 200mm x 200mm, 2mm and 100mm x 100mm, 2mm thickness and 500 mm height. Its yield strength is given as 250MPa in the manufacturer specification details.

**Cement -** Ordinary Portland Cement (OPC-53) confirming to IS 12269:1987 is used which has specific gravity of 3.13.

**Fine aggregate -** Natural river sand is used as fine aggregate. Fineness modulus of sand is 2.26 and has specific gravity of 2.59.

**Coarse Aggregate -** The Coarse aggregate are obtained from a local quarry is used. The coarse aggregate with a maximum size 20 mm and minimum size 10 mm having a specific gravity 2.84 has been taken for mixes.

## 4. TEST SETUP

### Test Procedure For Axial Loading Of Square CFST Column

In order to validate the basic mechanical concepts of CFST columns, 12 specimens will be tested under axial loading by Universal Testing Machine. In that, 3 RC column with size 200mm x 200mm, 3 square CFST column of size 200mm x 200mm with thickness 2 mm, 3 square CFST column of size 150mm x 150mm with thickness 2 mm and 3 square CFST column of size 100mm x 100mm with thickness 2 mm will be tested. Load will be applied axially to the column at an increment of 5 KN. All specimens will be subjected to load up to failure. The load will be applied gradually till the ultimate load. Compressive strength of the specimen will be calculated by dividing the maximum load carried by the specimen during the test with the average cross-sectional area.

**Figure 2**. Test Setup For Column On UTM Machine

## 5. RESULTS

Results are obtained for CFST Columns and RC Columns in the laboratory. For validation purpose compared with the results obtained from ETABS and manual calculation using IS Codes & Euro Codes.

## 5.1 Experimental Results

| Type | | Size ( mm ) | Area ( $cm^2$) | Length ( mm ) | Asc ( $mm^2$) | % of steel | Grade of steel | Concrete Grade | Load P in KN | Average Load In KN |
|---|---|---|---|---|---|---|---|---|---|---|
| Reinforced Concrete Column | RC 1 | 200 X 200 | 400 | 500 | 368 | 0.92 | FE-500 | M20 | 452.19 | 481.49 |
| | RC 2 | | | | | | | | 501.73 | |
| | RC 3 | | | | | | | | 490.55 | |
| CFST Column | CFST 1 | 100 X 100 | 100 | 500 | 784 | 7.84 | FE-250 | M20 | 281.15 | 301.8 |
| | CFST 2 | | | | | | | | 305.34 | |
| | CFST 3 | | | | | | | | 318.91 | |
| CFST Column | CFST 4 | 150 X 150 | 225 | 500 | 1184 | 5.26 | FE-250 | M20 | 490.82 | 504.36 |
| | CFST 5 | | | | | | | | 520.36 | |
| | CFST 6 | | | | | | | | 501.91 | |
| CFST Column | CFST 7 | 200 X 200 | 400 | 500 | 1584 | 3.96 | FE-250 | M20 | 675.15 | 689.60 |
| | CFST 8 | | | | | | | | 700.54 | |
| | CFST 9 | | | | | | | | 693.12 | |

## Load Versus Displacement

Axial load vs Axial Displacement curves for the square specimens are shown in Figure No. 3, 4 and 5. As seen in these figures, all the square CFST columns have no obvious axial shortening during the initial linear elastic period of the loading process, which is the cooperation of steel tube and the concrete core. When the axial load reaches about 90 to 95% of the peak load, the steel tube starts yielding, micro-cracking is initiated and propagated in concrete core, and the local buckling slightly occurs. Therefore, the axial and lateral strains measured at mid-height start to increase notably. The axial load of the square CFST columns rapidly decrease after the peak load with increased axial shortenings.

Where in the RC columns axial shortening occurs simultaneously as loading is started and micro cracks initiated when load reaches about 60 to 65% of peak load.

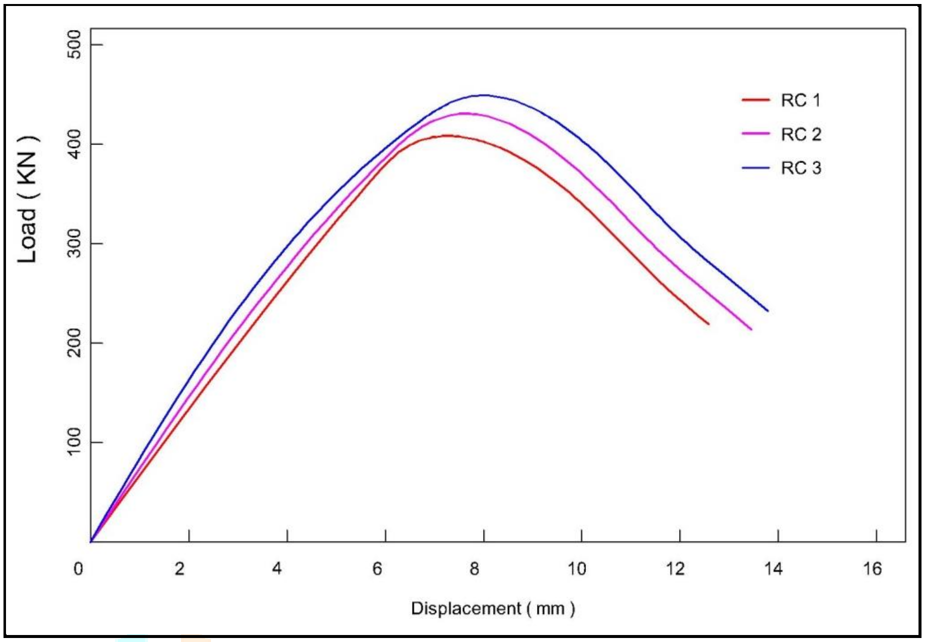

**Figure 3** Load vs Displacement Curve for RC Column

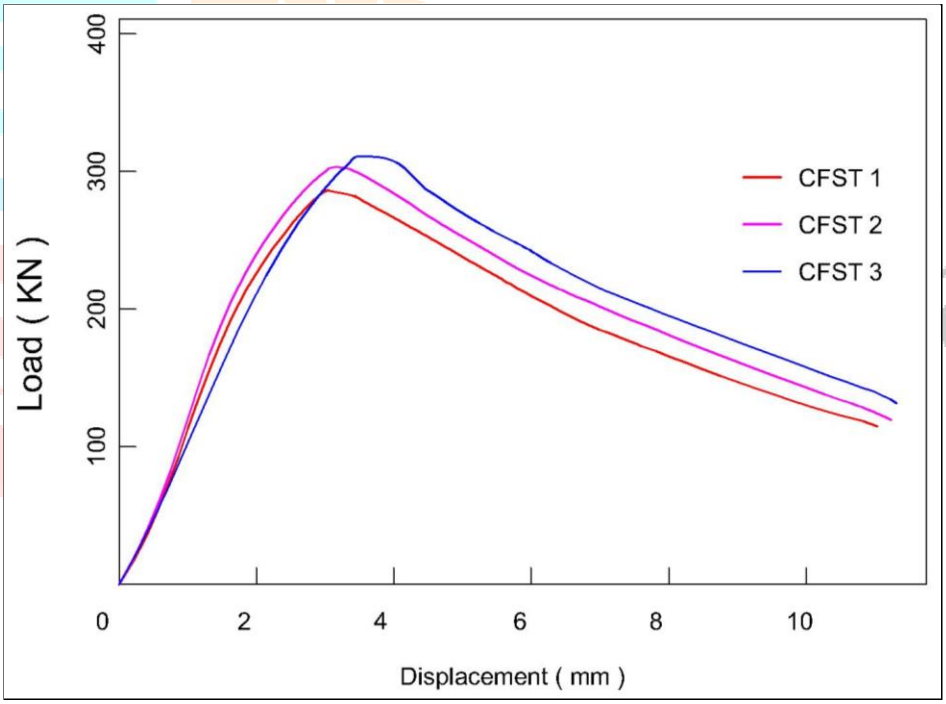

**Figure 4** Load vs Displacement Curve for CFST Column CFST-100

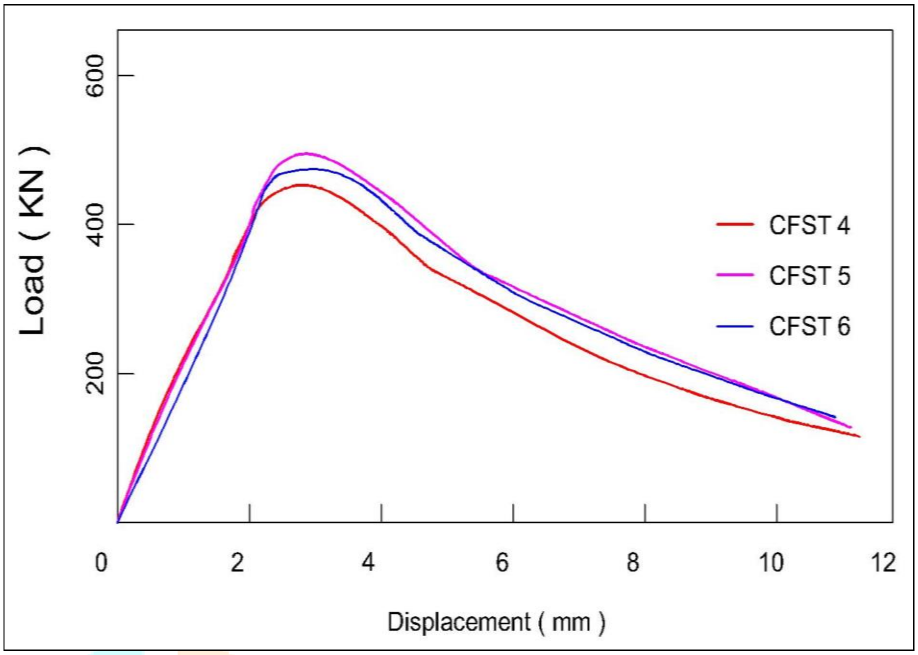

**Figure 5** Load vs Displacement Curve for CFST Column CFST-150

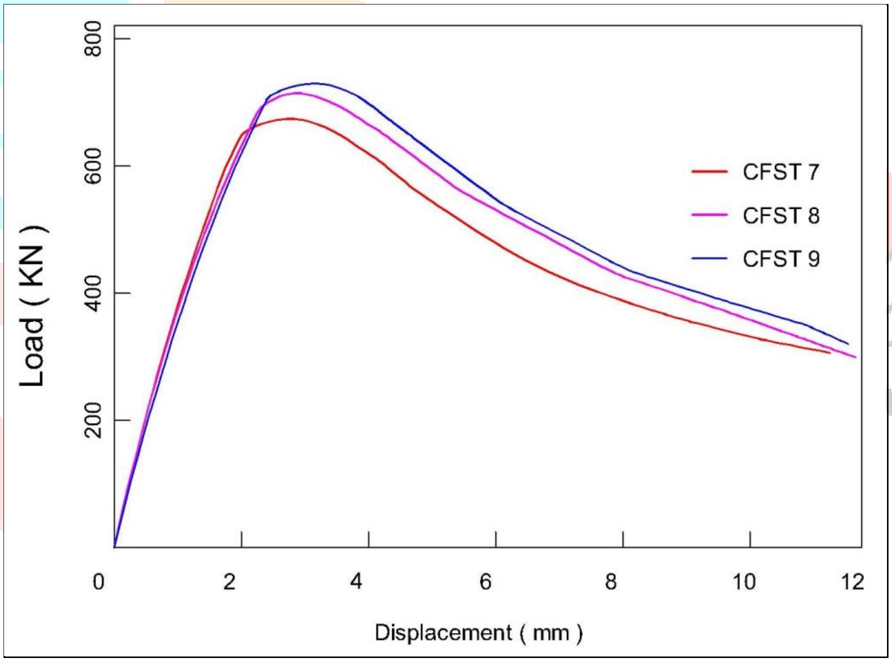

**Figure 6** Load vs Displacement Curve for CFST Column CFST-200

## 5.2 Results Obtained On Software – ETABS

| Type | Size ( mm ) | Area ( $cm^2$) | Length ( mm ) | Asc ( $mm^2$) | % of steel | Concrete Grade | Load P in KN |
|---|---|---|---|---|---|---|---|
| **Reinforced Concrete Column** | 200 X 200 | 400 | 500 | 368 | 0.92 | M20 | 385.790 |
| **CFST Column** | 100 X 100 | 100 | 500 | 784 | 7.84 | M20 | 261.012 |
| **CFST Column** | 150 X 150 | 225 | 500 | 1184 | 5.26 | M20 | 484.43 |
| **CFST Column** | 200 X 200 | 400 | 500 | 1584 | 3.96 | M20 | 634.665 |

## 5.3 Results Obtained By Calculations

IS 456-2000 is used for calculations of RC column and Euro Code 4 is used for calculations of CFST columns.

$$\lambda = \frac{le}{b} : \qquad e = \left(\frac{le}{500} + \frac{b}{30}\right) : \quad Pu = 0.4\, fck\ Ac + \left(\frac{0.67 fy\ As}{1000}\right)$$

| Type | Size ( mm ) | Area ( $cm^2$) | Length ( mm ) | Asc ( $mm^2$) | % of steel | Concrete Grade | Load Pu in KN |
|---|---|---|---|---|---|---|---|
| **Reinforced Concrete Column** | 200 X 200 | 400s | 500 | 368 | 0.92 | M20 | 385.770 |

EC 4 and NBR 8800 methods

For Square sections

$Npl.Rd = As\,fy + Ac\,fck$

$Ne = \pi^2 \frac{(EI)e}{le^2}$; $\quad (El)_e = E_s I_s + 0.6 E_c I_c$;

$\lambda = \sqrt{\frac{Npl.R}{N_e}}$; $\quad \chi = \frac{1}{\phi+\sqrt{\phi^2-\lambda^2}} \leq 1.0$;

$\phi = 0.5[1+\alpha(\lambda-0.2)+\lambda^2]\alpha = 0.21\ (Curve\ a)$

$N_{Rd} = \chi N_{pl.Rd}$

$E_c = 22000.[(f_{ck}/10)^{0.3}]$ to EC 4 and $E_c = 4760\sqrt{f_{ck}}$ to NBR 8000 – ($f_{ck}$ *and* $E_c$ in MPa)

| **Type** | **Size (mm)** | **Length (mm)** | **Ac ($cm^2$)** | **As ($mm^2$)** | **Ic ($mm^4$)** | **Is ($mm^4$)** | **Npl.Rd in KN** | **χ** | **$N_{Rd}$ in KN** |
|---|---|---|---|---|---|---|---|---|---|
| **CFST Column** | 100 x 100 | 500 | 100 | 784 | 7.077 x $10^6$ | 1.255 x $10^6$ | 380.30 | 0.72 | 274.272 |
| **CFST Column** | 150 x 150 | 500 | 225 | 1184 | 37.864 x $10^6$ | 4.323 x $10^6$ | 727.93 | 0.75 | 545.95 |
| **CFST Column** | 200 x 200 | 500 | 400 | 1584 | 122.98 x $10^6$ | 10.35 x $10^6$ | 1164.32 | 0.76 | 890.672 |

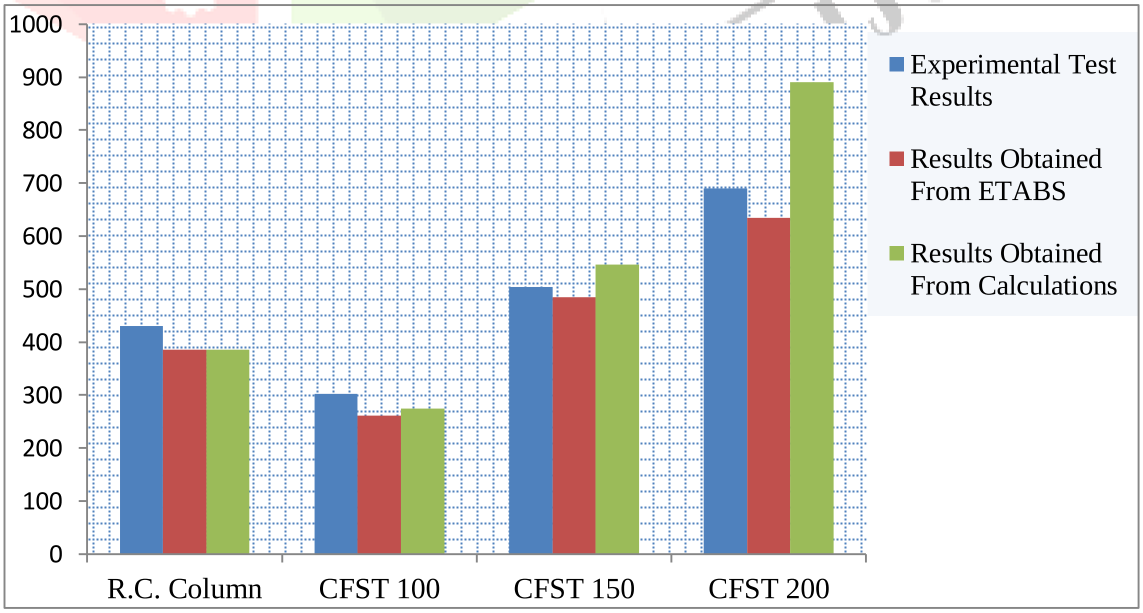

**Figure 7** Graph Showing The Ultimate Load Carrying Capacity Of Columns Under Axial Compressive Loading

# 6. CONCLUSION

From experimental testing of specimen and software analysis following conclusions have been concluded:

a) The strength of the concrete increased due to the confining effect provided from the steel tubes in CFST column, and the strength deterioration is not very severe, since the concrete Spalding is prevented by the steel tube.
b) The occurrence of local buckling of CFST column is delayed as compared to RC column.
c) As the CFST column has high bearing capacity, the size of column can be reduced by replacing it with RC column which increases the usable floor area in residential buildings.

## Cross – Sectional Properties:

a) The steel ratio in cross section of CFST column is much larger than those in the RC column.
b) Steel of the CFST section is well plasticized under bending since it is located on the outside the section.

## Construction Efficiency:

a) Formwork and reinforcing bars are omitted, which lead to savings of manpower and constructional cost and time.
b) Construction site remains clean.

## Cost Performance:

a) Because of the merits listed above, a better cost performance is obtained by replacing a RC column to the CFST column.

## Advantages Over RC Columns

a) Increased strength for a given cross sectional dimension.
b) Increased stiffness, leading to reduced slenderness and increased buckling resistance.
c) Identical cross sections with different load and moment resistances can be produced by varying steel thickness, the concrete strength and reinforcement. This allows the outer dimensions of a column to be held constant over a number of floors in a building, thus simplifying the construction and architectural detailing.
d) Drying shrinkage and creep of the concrete are much smaller than in ordinary reinforced concrete columns.
e) In structures that are subjected to seismic loadings, the composite column can provide a better ductility and load retention even after extensive concrete damage. The damages can be repaired if the overall structure survives.
f) CFST column is very useful for rehabilitation of structures such as bridge piers, high-rise buildings etc.
g) Forms and reinforcing bars are not required and concrete casting is done by pump-up method, which leads to savings of man power and constructional cost and time.
h) As the technique involves no formwork, the site is clear and more space is available for movement of men and machinery.

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