Experimental and analytical investigation on high performance concrete-filled steel tube stub columns under axial load

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Abstract. There has been an enormous improvement in the construction field in recent few decades among these; construction and material innovation are quite prominent. Concrete - steel composite part is one rising advance as perhaps the fastest technique for development. Steel tube with filled concrete is used to create a composite column. Experimental and theoretical work on high-performance CFST stub columns under axial load is explored in this paper. The parameters included in this study are diameter and thickness of steel tubes, mix design of high-performance concrete & ultimate load-carrying capacity. Six composite stub columns are cast and tested. The design formulas of CFST under axial loading are predicted using EUROCODE 4, ACI 318-95, AS 3600 & AS 4100. The finite element modeling of this composite column is done by using ABAQUS software.

Keywords: Axial load, composite stub column, confinement of concrete, conventional concrete, high performance concrete.

1. Introduction
Completely encased composite columns, partially encased composite columns, and concrete- filled steel tubular columns are the three styles of composite columns used in high- rise construction. CFSST columns are composite structural members made up of steel tubes filled with concrete. CFST is widely used in bridges, piles, off shore structures & high –rise buildings as columns, beam-column. It is also used as a beam in low- rise buildings [1]. Since the steel tube serves as a concrete confinement, the concrete core will delay the intense local buckling of the steel tube. The combined effect of steel & concrete results in the development of strength, whereby the concrete core will have high compressive strength, stiffness while stainless steel has high corrosion resistance and ductility [2]. The basic assumption & factors influencing the design of CFST under axial loading by using EUROCODE 4, ACI 318-95, AS 3600 & AS 4100.

1.1 Different kinds of CFST
Cross –sections of CFST include square, rectangular , elliptical, hexagonal and other shapes. Composite column structures, reinforced comosite columns, concrete- filled double skin tubes
(CFDST), reinforced concrete-filled double skin tubes, concrete-encased CFST columns, and stiffened CFST columns are examples of CFST used in construction[3].

![Figure 1. Types of CFST columns (source: EUROCODE 4)](image)

1.2 **Behaviour of CFST under axial loading**
The behaviour of the CFST column depends upon various parameters like cross-section shape, slenderness ratio, creep, and shrinkage [4]. The CFST column behaves in two different ways: Short columns: \((d/t<40)\) is small are controlled by the strength of the cross-section [5]. The column reaches the ultimate capacity when both materials reach their ultimate strength (steel-yielding, concrete-crushing). When a short CFST column undergoes axial loading, both the materials start to deform longitudinally. When concrete starts cracking until the constant expansion of steel tube. As the concrete core sustains more load due to the steel tubes encirclement [6]. Long columns \((d/t>40)\) are controlled by stability and fail by column buckling [7].

1.3 **Design considerations for Ultimate load carrying capacity of CFST column**
The basic assumptions for CFST columns under axial loading condition:
1. Plan section remains constant before and after loading
2. Existing perfect bond between concrete and steel shell at the material interface
3. Neglecting the following terms like creep, shrinkage, torsion effects
4. Monotonic loading

From EUROCODE 4
The CFST load bearing carrying capacity under axial load: for circular columns
\[ N(\text{EC4}) = A_s \cdot f_y + A_c \cdot f_{cy} \]
From American concrete institute (ACI 318-95) & Australian standards (AS 3600 & AS 4100) codes
The CFST load bearing carrying capacity under axial load: for circular columns
\[ N \text{ (ACI/AS)} = A_s \cdot f_y + 1.30 A_c \cdot f_{cy} \]
\(A_s, A_c\) = area of steel and concrete
\(f_y, f_{cy}\) = yield and compressive strength of both materials

2. **Methodology**
The term “high performance concrete” (HPC) refers to concrete that meets the performance requirements of the vast majority of construction projects. “High – performance concrete” has many of the same properties as high-grade concrete, but it also has some more characteristics, such as high density, high workability, high strength, low permeability, and sulphate and chemical resistance [8].

Two approaches for the production of HPC:
1. Reduced capillary pores.
2. Binding sites of chloride ions.
An M50 grade of concrete with the mineral admixture of silica fumes 4% and fly ash 25% is used for this composite column. Conventional concrete is also performed with the same specimen for a strength comparison of 28 days. 304 grade stainless steel is another critical material. This grade has a chromium content of 18% and nickel content of 8%.

3. Details of specimen
Table 3 presents the specifications of stainless steel hollow tubes cut from the same material with a height of 300 mm and a thickness of 2 mm to know the properties of steel. Type 304 stainless steel is corrosion resistant and has excellent shaping and welding properties. The concrete is prepared by using a concrete mixer with desired proportions. The mix of high performance concrete is placed in hollow tubes with good compaction. The top surface concrete get left overflowed is to be grinding to get a flat surface and cured for 28 days [9]. The proportions of high performance and conventional concrete in the mix are shown in table 1 and 2.

| Table 1. Mix design high performance concrete (kg/m3) |
|-----------------|-----------------|-----------------|---------------|---------------|---------------|
| Cement          | Fine aggregates | Coarse aggregates | Water | Silica fumes | Fly ash |
| 341             | 620             | 1139            | 144    | 16           | 95         |

| Table 2. Mix design conventional concrete (kg/m3) |
|-----------------|-----------------|-----------------|---------------|
| Cement          | Fine aggregates | Coarse aggregates | Water |
| 422             | 620             | 1284            | 147.6         |

| Table 3. Dimensions of steel tubes (mm) |
|-----------------|---------------|
| S.NO            | Outer Dia    |
| Sample 1        | 73            |
| Sample 2        | 86            |
| Sample 3        | 100           |

4. Testing procedure
Figure 2 shows a universal testing machine (UTM) with 200 tonnes capacity that was used to test three composite stub columns of different diameters made of high performance concrete. The deformations are noted by using a dial gauge under axial loading. The modes of failure of stub column under axial loading conditions are mild local buckling. For the strength comparison, the same diameter specimens are compared with conventional concrete and then testing is done.
5. Experimental & analytical results
The maximum load bearing capacities of stub columns under axial loading conditions were investigated and obtaining the load vs deformation graphs based on sequential values. By using finite element techniques numerical simulation is done by using ABAQUS software [10]. The FEA model consists of three parts: pre-processing and post-processing and solution. Developing the 3d model has HPC as core and stainless steel as shell element. The pre-processing consists of parts, properties (HPC, stainless steel), step, interaction between concrete & steel), load, meshing. Table 4 shows that high performance concrete and stainless steel has different structural properties. The post-processing consists of job, visualization to obtain the deformation and failure [11]. Numerical modelling of composite column aim to known the buckling deformed shape, displacement values. Finally, the results of simulations are shown as load vs deformations are compared with experimental results [12].

**Table 4. Different structural properties of high performance concrete and steel tubes for numerical simulation**

| High performance concrete (HPC) | Stainless steel |
|---------------------------------|-----------------|
| Elastic modulus – 35355 MPa     | Elastic modulus – 205 GPa |
| Possion ratio – 0.1             | Possion ratio – 0.3 |
| Yield stress – 22.5 MPa         | Yield stress -235 MPa |
| Crushing failure stress – 65 MPa| Ultimate stress- 410 MPa |
| Plastic strain at failure – 0.0039 |                               |
| Cracking failure stress- 2.68 MPa |                          |

Experimental and analytical results for HPC stub column with 71mm diameter of thickness 2mm under axial load of 353.2 KN are shown in figure 3 & 4.
Figure 3: Axial deformation of column with HPC

Experimental and analytical results for HPC stub column with 82mm Diameter of thickness 2 mm under axial load of 698.4 KN are shown in figure 5 & 6

Figure 5: Axial deformation of stub column with HPC

Figure 6: Axial deformation in abaqus

Figure 4: Axial deformation in abaqus

Experimental and analytical results for HPC stub column with diameter 98 mm of thickness 2mm under axial load of 686.7 KN are shown in figure 7 & 8
Figure 7. Axial deformation of stub column with HPC

Figure 8. Axial deformation in abaqus

Experimental and analytical results for conventional concrete stub column with 71 mm diameter of thickness 2mm under axial load of 206KN are shown in figure 9 & 10.

Figure 9. Axial deformation with conventional concrete

Figure 10. Axial deformation in abaqus

Experimental and analytical results for conventional concrete stub column with 82 mm diameter of thickness 2mm under axial load of 578.06KN are shown in figure 11 & 12
Experimental and analytical results for conventional concrete stub column with 98 mm diameter of thickness 2mm under axial load of 582.59 KN are shown in figure 13 & 14.

The experimental and analytical results having an overall percentage error is 5% for both conventional and high performance concrete. It states that the increase of diameter the load carrying capacity is also increased [13 & 14]. The compressive strength of all specimens is enhanced by using high performance concrete. The ultimate load and deformations of all stub columns will be represented as graphs as shown below.

Load vs deformation graphs for HPC stub column with 71mm diameter of thickness 2mm under axial load of 353.2 KN are shown below.
Figure 15. Load vs deformation with HPC

Load vs deformation graphs for HPC stub column with 82mm Diameter of thickness 2mm under axial load of 698.4 KN are shown below.

Figure 16. Load vs deformation with HPC

Load vs deformation for HPC stub column with diameter 98 mm of thickness 2 mm under axial load of 686.7 KN are shown below.
Figure 17. Load vs deformation with HPC

Load vs deformation for conventional concrete stub column with 71 mm diameter of thickness 2 mm under axial load of 206 KN are shown below.

Figure 18. Load vs deformation with conventional concrete

Load vs deformation for conventional concrete stub column with 82 mm diameter of thickness 2 mm under axial load of 578.06 KN are shown below.
Figure 19. Load vs deformation with conventional concrete

Load vs deformation for conventional concrete stub column with 98 mm diameter of thickness 2 mm under axial load of 582.59 KN are shown below.

Figure 20. Load vs. deformation with conventional concrete

| Experimental results | Analytical results |
|---------------------|-------------------|
| Load (KN) | Deformation (mm) | Load (KN) | Deformation (mm) |
| 353.2 | 13.8 | 304.1 | 9.8 |
| 686.7 | 38.4 | 682.2 | 28.4 |
| 698.4 | 28.8 | 694.6 | 25.2 |

Table 5. Ultimate load in laboratory and software (HPC)

| Experimental results | Analytical results |
|---------------------|-------------------|
| Load (KN) | Deformation (mm) | Load (KN) | Deformation (mm) |
| 206 | 19.5 | 196 | 17.2 |
| 577.08 | 20.4 | 552 | 16.4 |
| 582.59 | 18.7 | 571.2 | 17.5 |

Table 6. Ultimate load in laboratory and software (conventional concrete)
Figure 21. Ultimate load carrying capacity of all columns

6. Conclusion
This paper represents & examines the results that were obtained from the analytical and experimental studies on high performance concrete CFST under axial loading. Firstly, high performance concrete mixes are discussed because the concrete is important for compressive strength. Technology of CFST, which has been commonly used in high-rise building, bridge construction & coastal structures. The following important conclude remarks are:

1. As compared to conventional concrete, the maximum load bearing capacities of all three stub columns are improved.
2. We discovered that all specimens failed due to internal local buckling and face of the specimen includes cracks in the experiments. Column buckling influenced by the diameter-to-thickness ratio.
3. Stainless steel is used in larger quantities than other materials. It can bear a lot more weight than other materials.
4. A nearly identical range of analytical and experimental results were obtained. The proposed finite element modelling techniques were certain to be relatively effective in predicting the behaviour of the CFST columns.

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